CHAPTER 6
AIRCRAFT WELDING

GENERAL

Metals can be joined by mechanical means (bolting or riveting, or by welding, brazing, soldering or adhesive bonding). All of these methods are used in aircraft construction. This chapter will discuss the methods used to join metals by welding, brazing, and soldering.

Welding

Welding is the process of joining metal by fusing the materials while they are in a plastic or molten state. There are three general types of welding: (1) Gas, (2) electric arc, and (3) electric resistance welding. Each of these types of welding has several variations which are used in aircraft construction.

Welding is used extensively in the repair and manufacture of aircraft. Such parts as engine mounts and landing gear are often fabricated in this manner, and many fuselages, control surfaces, fittings, tanks, etc., are also of welded construction. Structures that have been welded in manufacture may generally be repaired economically by using the same welding process. Careful workmanship, both in preparation and actual welding, is of utmost importance.

Welding is one of the most practical of the many metal-joining processes available. The welded joint offers rigidity, simplicity, low weight, and high strength. Consequently, welding has been universally adopted in the manufacture and repair of all types of aircraft. Many structural parts as well as nonstructural parts are joined by some form of welding, and the repair of many of these parts is an indispensable part of aircraft maintenance.

It is equally important to know when not to weld, as it is to know when. Many of the alloy steels or high-carbon steel parts that have been hardened or strengthened by heat treatment cannot be restored to 100% of their former hardness and strength after they have been welded.

Gas Welding

Gas welding is accomplished by heating the ends or edges of metal parts to a molten state with a high-temperature flame. This flame is produced with a torch burning a special gas such as acetylene or hydrogen with pure oxygen. The metals, when in a molten state, flow together to form a union without the application of mechanical pressure or blows.

Aircraft parts fabricated from chrome-molybdenum or mild carbon steel are often gas welded. There are two types of gas welding in common use: (1) Oxyacetylene and (2) oxyhydrogen. Nearly all gas welding in aircraft construction is done with an oxyacetylene flame, although some manufacturers prefer an oxyhydrogen flame for welding aluminum alloys.

Electric Arc Welding

Electric arc welding is used extensively in both the manufacture and repair of aircraft, and can be satisfactorily used in the joining of all weldable metals. The process is based on using the heat generated by an electric arc. Variations of the process are: (1) Metallic arc welding, (2) carbon arc welding, (3) atomic hydrogen welding, (4) inert-gas (helium) welding, and (5) multi-arc welding. Metallic arc and inert-gas welding are the two electric arc welding processes most widely used in aircraft construction.

Electric Resistance Welding

Electric resistance welding is a welding process in which a low-voltage, high-amperage current is applied to the metals to be welded through a heavy, low-resistance copper conductor. The materials to be welded offer a high resistance to the flow of current, and the heat generated by this resistance fuses (welds) the parts together at their point of contact.

Three commonly used types of electric resistance welding are butt, spot, and seam welding. Butt welding is used in aircraft work to weld terminals to control rods. Spot welding is frequently used in airframe construction. It is the only welding method used for joining structural corrosion-resistant steel. Seam welding is similar to spot welding, except that power-driven rollers are used as electrodes. A continuous airtight weld can be obtained using seam welding.

OXYACETYLENE WELDING EQUIPMENT

Oxyacetylene welding equipment may be either stationary or portable. A portable equipment rig consists of the following:

(1) Two cylinders, one containing oxygen and one acetylene.
(2) Acetylene and oxygen pressure regulators, complete with pressure gages and connections.
(3) A welding torch, with a mixing head, extra tips and connections.
(4) Two lengths of colored hose, with adapter connections for the torch and regulators.
(5) A special wrench.
(6) A pair of welding goggles.
(7) A flint lighter.
(8) A fire extinguisher.

Figure 6–1 shows some of the equipment in a typical portable acetylene welding rig.

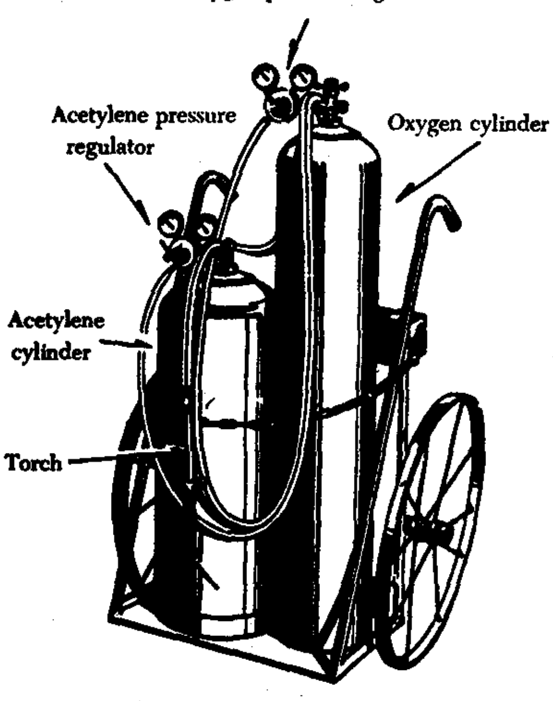


FIGURE 6–1. Typical portable acetylene welding rig.

Stationary oxyacetylene welding equipment is similar to portable equipment, except that acetylene and oxygen are piped to one or several welding stations from a central supply. The central supply usually consists of several cylinders connected to a common manifold. A master regulator controls the pressure in each manifold to ensure a constant pressure to the welding torch.

Acetylene Gas

Acetylene gas is a flammable, colorless gas which has a distinctive, disagreeable odor, readily detectable even when the gas is heavily diluted with air. Unlike oxygen, acetylene does not exist free in the atmosphere; it must be manufactured. The process is neither difficult nor expensive. Calcium carbide is made to react chemically with water to produce acetylene.

Acetylene is either used directly in a manifold system or stored in cylinders. If ignited, the result is a yellow, smoky flame with a low temperature. When the gas is mixed with oxygen in the proper proportions and ignited, the result is a blue-white flame with temperatures which range from approximately 5,700° to 6,300° F.

Under low pressure at normal temperatures, acetylene is a stable compound. But when compressed in a container to pressures greater than 15 p.s.i., it becomes dangerously unstable. For this reason, manufacturers fill the acetylene storage cylinders with a porous substance (generally a mixture of asbestos and charcoal) and saturate this substance with acetone. Since acetone is capable of absorbing approximately 25 times its own volume of acetylene gas, a cylinder containing the correct amount of acetone can be pressurized to 250 p.s.i.

Acetylene Cylinders

The acetylene cylinder is usually a seamless steel shell with welded ends, approximately 12 in. in diameter and 36 in. long. It is usually painted a distinctive color, and the name of the gas is stenciled or painted on the sides of the cylinder. A fully charged acetylene cylinder of this size contains approximately 225 cu. ft. of gas at pressures up to 250 p.s.i. In the event of fire or any excessive temperature rise, special safety fuse plugs installed in the cylinder will melt, allowing the excess gas to escape or burn, thus minimizing the chances of an explosion. The holes in the safety plugs are made small to prevent the flames from burning back into the cylinder. Acetylene cylinders should not be completely emptied, or a loss of filler material may result.

Oxygen Cylinders

The oxygen cylinders used in welding operations are made of seamless steel of different sizes. A typical small cylinder holds 200 cu. ft. of oxygen at 1,800 p.s.i. pressure. A large size holds 250 cu. ft. of oxygen at 2,265 p.s.i. pressure. Oxygen cylinders are usually painted green for identification The cylinder has a high-pressure valve located at the top of the cylinder. This valve is protected by a metal safety cap which should always be in place when the cylinder is not in use.

Oxygen should never come in contact with oil or grease. In the presence of pure oxygen, these substances become highly combustible. Oxygen hose and valve fittings should never be oiled or greased, or handled with oily or greasy hands. Even grease spots on clothing may flare up or explode if struck by a stream of oxygen. Beeswax is a commonly used lubricant for oxygen equipment and fittings.

Pressure Regulators

Acetylene and oxygen regulators reduce pressures and control the flow of gases from the cylinders to the torch. Acetylene and oxygen regulators are of the same general type, although those designed for acetylene are not made to withstand such high pressures as those designed for use with oxygen. To prevent interchange of oxygen and acetylene hoses, the regulators are built with different threads on the outlet fitting. The oxygen regulator has a right-hand thread, and the acetylene regulator has a left-hand thread.

On most portable welding units, each regulator is equipped with two pressure gages, a high-pressure gage which indicates the cylinder pressure and a low-pressure gage which indicates the pressure in the hose leading to the torch (working pressure).

In a stationary installation, where the gases are piped to individual welding stations, only one gage for oxygen and one for acetylene are required for each welding station, since it is necessary to indicate only the working pressure of the gases flowing through the hose to the welding torch.

A typical regulator, complete with pressure gages and connections, is shown in figure 6–2. The adjusting screw shown on the front of the regulator is for adjusting the working pressure. When this adjusting screw is turned to the left (counterclockwise) until it turns easily, the valve mechanism inside the regulator is closed. No gas can then flow to the torch. As the handle is turned to the right (clockwise), the screw presses against the regulating mechanism, the valve opens, and gas passes to the torch at the pressure shown on the working pressure gage. Changes in the working pressure can

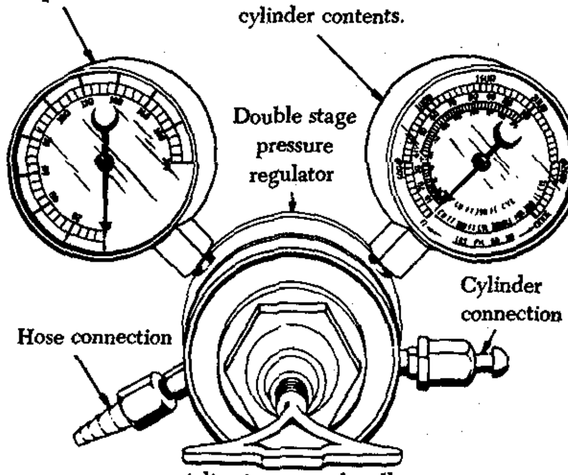


FIGURE 6–2. Typical oxygen pressure regulator.

be made by adjusting the handle until the desired pressure is registered.

Before opening the high-pressure valve on a cylinder, the adjusting screw on the regulator should be fully released by turning it counterclockwise. This closes the valve inside the regulator, protecting the mechanism against possible damage.

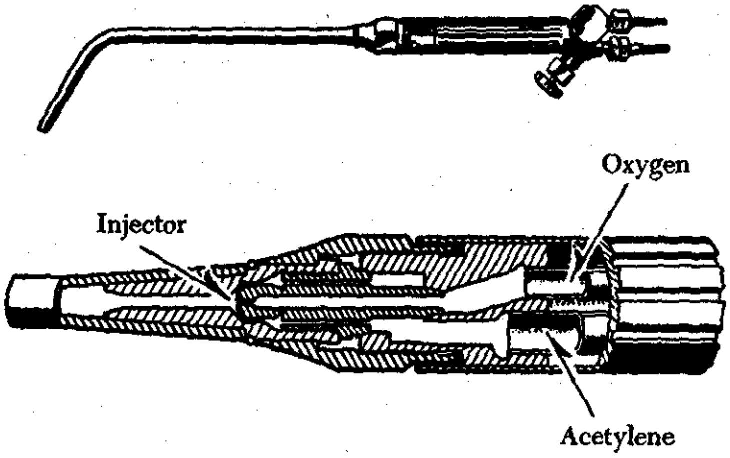
Welding Torch

The welding torch is the unit used to mix the oxygen and acetylene together in correct proportions. The torch also provides a means of directing and controlling the size and quality of the flame produced. The torches are designed with two needle valves, one for adjusting the flow of acetylene and the for other adjusting the flow of oxygen.

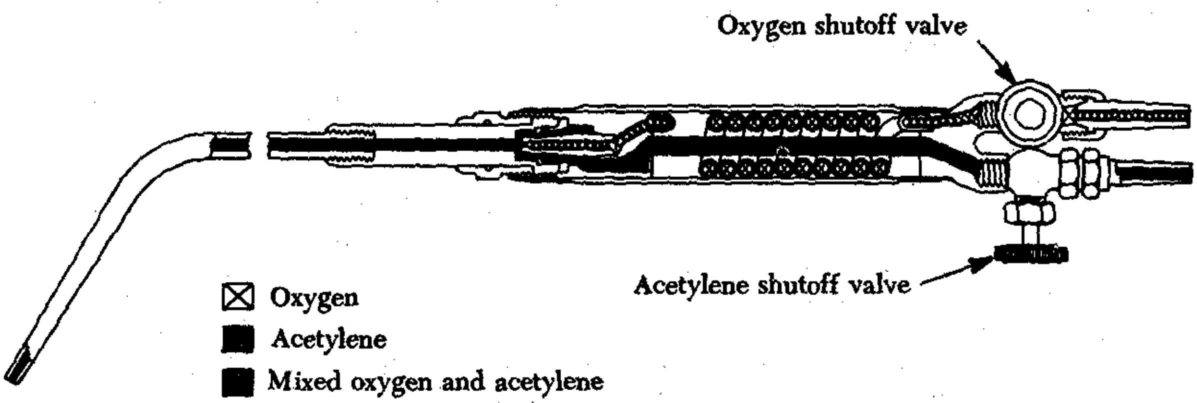
Welding torches are manufactured in different sizes and styles, thereby providing a suitable type for different applications. They are also available with several different sizes of interchangeable tips in order that a suitable amount of heat can be obtained for welding the various kinds and thicknesses of metals.

Welding torches can be divided into two classes: (1) The injector type and (2) the balanced-pressure type. The injector-type torch (figure 6–3A) is designed to operate with very low acetylene pressure as compared to the oxygen pressure.

A narrow passageway or nozzle within the torch, called the injector, through which the oxygen



A Injector-type welding torch.



B Balanced-pressure welding torch.

FIGURE 6–3. Welding torches.

passes, causes the speed of oxygen flow to increase to a high velocity with a corresponding drop in pressure. This pressure drop across the injector creates a pressure differential which acts to draw the required amount of acetylene into the mixing chamber in the torch head.

In the balanced-pressure torch, the oxygen and acetylene are both fed to the torch at the same pressure (figure 6–3B). The openings to the mixing chamber for each gas are equal in size, and the delivery of each gas is independently controlled. This type of torch is generally better suited for aircraft welding than the injector type because of the ease of adjustment.

Welding Torch Tips

The torch tip delivers and controls the final flow of gases. It is important that the correct tip be selected and used with the proper gas pressures if a job is to be welded satisfactorily. The nature of the weld, the material, the experience of the welder, and the position in which the weld is to be made, all determine the correct size of the tip opening. The size of tip opening, in turn, determines the amount of heat (not the temperature) applied to the work. If a tip which is too small is used, the heat provided will be insufficient to produce penetration to the proper depth. If the tip is too large, the heat will be too great, and holes will be burned in the metal.

The torch tip sizes are designated by numbers, and each manufacturer has his own arrangement for classifying them. As an example, a number two tip is made with an orifice of approximately 0.040 in. diameter. The diameter of the tip orifice is related to the volume of heat it will deliver.

Torch tips are made of copper or copper alloy and are made so that they seat well when tightened handtight. Torch tips should not be rubbed across fire brick or used as tongs to position work.

With use, the torch tip will become clogged with carbon deposits and, if it is brought in contact with the molten pool, particles of slag may lodge in the opening. A split or distorted flame is an indication of a clogged tip. Tips should be cleaned with the proper size tip cleaners or with a piece of copper or soft brass wire. Fine steel wool may be used to remove oxides from the outside of the tip. These oxides hinder the heat dissipation and cause the tip to overheat.

A flint lighter is provided for igniting the torch. The lighter consists of a file-shaped piece of steel, usually recessed in a cuplike device, and a piece of flint that can be drawn across the steel, producing the sparks required to light the torch. Matches should never be used to ignite a torch since their length requires bringing the hand in close to the tip to ignite the gas. Accumulated gas may envelop the hand and, when ignited, cause a severe burn.

Goggles

Welding goggles, fitted with colored lenses, are worn to protect the eyes from heat, light rays, sparks, and molten metal. A shade or density of color that is best suited for the particular situation should be selected. The darkest shade of lens which will show a clear definition of the work without eyestrain is the most desirable. Goggles should fit closely around the eyes and should be worn at all times during welding and cutting operations.

Welding (Filler) Rods

The use of the proper type filler rod is very important in oxyacetylene welding operations. This material not only adds reinforcement to the weld area, but also adds desired properties to the finished weld. By selecting the proper rod, either tensile strength or ductility can be secured in a weld, or both can be secured to a reasonably high degree. Similarly, rods can be selected which will help retain the desired amount of corrosion resistance. In some cases, a suitable rod with a lower melting point will eliminate possible cracks caused by expansion and contraction.

Welding rods may be classified as ferrous or nonferrous. The ferrous rods include carbon and alloy steel rods as well as cast-iron rods. Nonferrous rods include brazing and bronze rods, aluminum and aluminum alloy rods, magnesium and magnesium alloy rods, copper rods, and silver rods.

Welding rods are manufactured in standard 36-in. lengths and in diameters from $\frac{1}{16}$ in. to $\frac{3}{8}$ in. The diameter of the rod to be used is governed by the thickness of the metals being joined. If the rod is too small, it will not conduct heat away from the puddle rapidly enough, and a burned weld will result. A rod that is too large will chill the puddle. As in selecting the proper size welding torch tip, experience enables the welder to select the proper diameter welding rod.

Setting Up Acetylene Welding Equipment

Setting up acetylene welding equipment and preparing for welding should be done systematically and in a definite order to avoid costly mistakes. The following procedures and instructions are typical of those used to assure safety of equipment and personnel:

(1) Secure the cylinders so they cannot be upset, and remove the protective caps from the cylinders.

(2) Open each cylinder shutoff valve for an instant to blow out any foreign matter that may be lodged in the outlet. Close the valves and wipe off the connections with a clean cloth.

(3) Connect the acetylene pressure regulator to the acetylene cylinder and the oxygen regulator to the oxygen cylinder. Use a regulator wrench and tighten the connecting nuts enough to prevent leakage.

(4) Connect the red (or maroon) hose to the acetylene pressure regulator and the green (or black) hose to the oxygen regulator. Tighten the connecting nuts enough to prevent leakage. Do not force these connections, since these threads are made of brass and are easily damaged.

(5) Release both pressure regulator adjusting screws by turning the adjusting screw handle on each regulator counterclockwise until it turns freely. This is to avoid damage to the regulators and pressure gages when the cylinder valves are opened.

(6) Open the cylinder valves slowly and read each of the cylinder pressure gages to check the contents in each cylinder. The oxygen cylinder shutoff valve should be opened fully and the acetylene cylinder

shutoff valve is opened approximately one and one-half turns.

(7) Blow out each hose by turning the pressure adjusting screw handle inward (clockwise) and then turning it out again. The acetylene hose should be blown out only in a well-ventilated space which is free from sparks, flame, or other sources of ignition.

(8) Connect both hoses to the torch and check the connections for leaks by turning the pressure regulator screws in, with the torch needle valves closed. When 20 p.s.i. shows on the oxygen working pressure gage and 5 p.s.i. on the acetylene gage, close the valves by turning the pressure regulator screws out. A drop in pressure on the working gage indicates a leak between the regulator and torch tip. A general tightening of all connections should remedy the situation. If it becomes necessary to locate a leak, use the soap suds method. Do this by painting all fittings and connections with a thick solution of the soapy water. **Never hunt for an acetylene leak with a flame,** since a serious explosion can occur in the hose or in the cylinder.

(9) Adjust the working pressure on both the oxygen and acetylene regulators by turning the pressure-adjusting screw on the regulator clockwise until the desired settings are obtained.

Oxyacetylene Flame Adjustment

To light the torch, open the torch acetylene valve a quarter to a half turn. Hold the torch to direct the flame away from the body and ignite the acetylene gas, using the flint lighter. The pure acetylene flame is long and bushy and has a yellowish color. Continue opening the acetylene valve until the flame leaves the tip approximately one-sixteenth of an inch. Open the torch oxygen valve. When the oxygen valve is opened, the acetylene flame is shortened, and the mixed gases burn in contact with the tip face. The flame changes to a bluish-white color and forms a bright inner cone surrounded by an outer flame envelope.

Oxyacetylene Welding Process

The oxyacetylene process of welding is a method in which acetylene and oxygen gases are used to produce the welding flame. The temperature of this flame is approximately 6,300° F., which is sufficiently high to melt any of the commercial metals to effect a weld. When the oxyacetylene flame is applied to the ends or edges of metal parts, they are quickly raised to a melting state and flow together to form one solid piece when solidified. Usually some additional metal is added to the weld, in the form of a wire or rod, to build up the weld seam to a greater thickness than the base metal.

There are three types of flames commonly used for welding. These are neutral, reducing or carburizing, and oxidizing. The characteristics of the different kinds of flames are shown in figure 6–4.

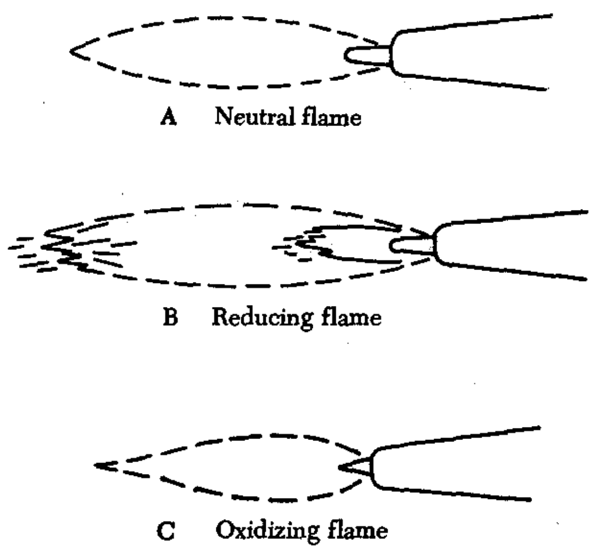


FIGURE 6–4. Characteristics of oxyacetylene flames.

The neutral flame (figure 6–4A) is produced by burning acetylene with oxygen in such proportions as to oxidize all particles of carbon and hydrogen in the acetylene. This flame is distinguished by the well-rounded, smooth, clearly defined white central cone at the end of the tip. The envelope or outer flame is blue with a purple tinge at the point and edges. A neutral flame is generally used for welding and gives a thoroughly fused weld, free from burned metal or hard spots.

To obtain a neutral flame, gradually open the oxygen valve. This shortens the acetylene flame and causes a "feather" to appear in the flame envelope. Gradually increase the amount of oxygen until the "feather" disappears inside a clearly defined inner luminous cone.

The reducing or carburizing flame is shown in figure 6–4B. Since the oxygen furnished through the torch is not sufficient to complete the combustion of the acetylene, carbon escapes unburned. This flame can be recognized by the greenish-white brushlike second cone at the tip of the first cone. The outer flame is slightly luminous and has about the same appearance as an acetylene flame burning freely in air alone. This type of flame introduces carbon into the steel.

To obtain a reducing flame, first adjust the flame to neutral; then open the acetylene valve slightly to produce a white streamer or "feather" of acetylene at the end of the inner cone.

An oxidizing flame (figure 6–4C) contains an excess of oxygen, which is the result of too much oxygen passing through the torch. The oxygen not consumed in the flame escapes to combine with the metal. This flame can be recognized by the short, pointed, bluish-white central cone. The envelope or outer flame is also shorter and of a lighter blue color than the neutral flame. It is accompanied by a harsh sound similar to high-pressure air escaping through a small nozzle. This flame oxidizes or burns most metals and results in a porous weld. It is used only when welding brass or bronze.

To obtain the oxidizing flame, first adjust the flame to neutral; then increase the flow of oxygen until the inner cone is shortened by about one-tenth of its length. The oxidizing flame has a pointed inner cone.

With each size of tip, a neutral, oxidizing or carburizing flame can be obtained. It is also possible to obtain a "harsh" or "soft" flame by increasing or decreasing the pressure of both gases.

For most regulator settings the gases are expelled from the torch tip at a relatively high velocity, and the flame is called "harsh." For some work it is desirable to have a "soft" or low-velocity flame without a reduction in thermal output. This may be achieved by using a larger tip and closing the gas needle valves until the neutral flame is quiet and steady. It is especially desirable to use a soft flame when welding aluminum, to avoid blowing holes in the metal when the puddle is formed.

Improper adjustment or handling of the torch may cause the flame to backfire or, in very rare cases, to flashback. A backfire is a momentary backward flow of the gases at the torch tip, which causes the flame to go out. A backfire may be causes by touching the tip against the work, by overheating the tip, by operating the torch at other than recommended pressures, by a loose tip or head, or by dirt or slag in the end of the tip. A backfire is rarely dangerous, but the molten metal may be splattered when the flame pops.

A flashback is the burning of the gases within the torch and is dangerous. It is usually caused by loose connections, improper pressures, or overheating of the torch. A shrill hissing or squealing noise accompanies a flashback; and unless the gases are turned off immediately, the flame may burn back through the hose and regulators and cause great damage. The cause of a flashback should always be determined and the trouble remedied before relighting the torch.

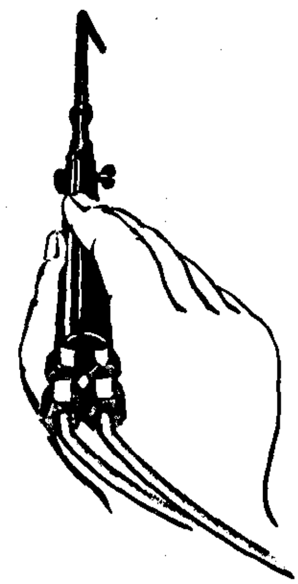


FIGURE 6–5. Holding the acetylene torch to weld light-gage metals.

Extinguishing The Torch

The torch can be shut off simply by closing both needle valves, but it is better practice to turn the acetylene off first and allow the gas remaining in the torch tip to burn out. The oxygen needle valve can then be turned off. If the torch is not to be used again for a long period, the pressure should be turned off at the cylinder. The hose lines should then be relieved of pressure by opening the torch needle valves and the working pressure regulator, one at a time, allowing the gas to escape. Again, it is a good practice to relieve the acetylene pressure and then the oxygen pressure. The hose should then be coiled or hung carefully to prevent damage or kinking.

Fundamental Oxyacetylene Welding Techniques

The proper method of holding the acetylene welding torch depends on the thickness of the metal being welded. When welding light-gage metal, the torch is usually held as illustrated in figure 6–5, with the hose draped over the wrist.

Figure 6–6 shows the method of holding the torch during the welding of heavy materials.

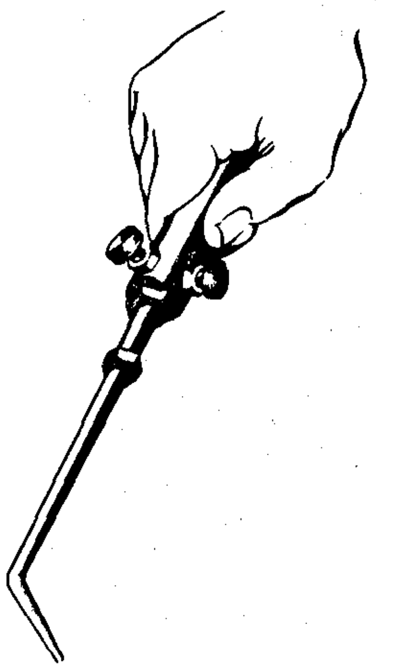


FIGURE 6–6. Holding the acetylene torch to weld heavy materials.

The torch should be held so that the tip is in line with the joint to be welded, and inclined between 30° and 60° from the perpendicular. The best angle depends on the type of weld to be made, the amount of preheating necessary, and the thickness and type of metal. The thicker the metal, the more nearly vertical the torch must be for proper heat penetration. The white cone of the flame should be held about ⅛ in. from the surface of the base metal.

If the torch is held in the correct position, a small puddle of molten metal will form. The puddle should be composed of equal parts of the pieces being welded. After the puddle appears, movement of the tip in a semicircular or circular motion should be started. This movement ensures an even distribution of heat on both pieces of metal. The speed and motion of the torch movement are learned only by practice and experience.

Forehand welding is the technique of pointing the torch flame forward in the direction in which the weld is progressing, as illustrated in figure 6–7. The filler rod is added to the puddle as the edges of the joint melt before the flame. The forehand method is used in welding most of the lighter tubings and sheet metals.

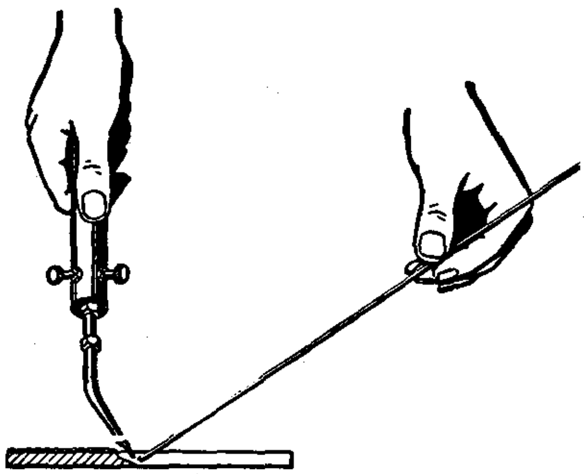


FIGURE 6–7. Forehand welding.

Backhand welding is the technique of pointing the torch flame toward the finished weld and moving away in the direction of the unwelded area, melting the edges of the joint as it is moved (figure 6–8). The welding rod is added to the puddle between the flame and the finished weld.

Backhand welding is seldom used on sheet metal because the increased heat generated in this method is likely to cause overheating and burning. It is preferred for metals having a thick cross section. The large puddle of molten metal required for such welds is more easily controlled in backhand welding, and it is possible to examine the progress of the weld and determine if penetration is complete.

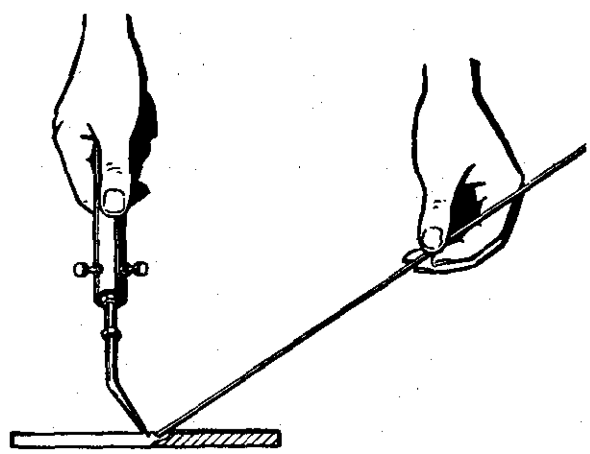


FIGURE 6–8. Backhand welding.

WELDING POSITIONS

There are four general positions in which welds are made. These positions are shown in figure 6–9 and are designated as flat, overhead, horizontal, and vertical.

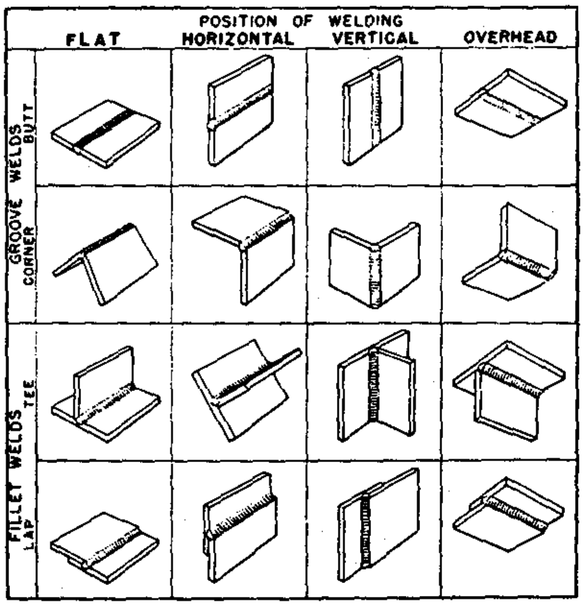


FIGURE 6–9. Four basic welding positions.

Welding is done in the flat position whenever possible, since the puddle is much easier to control in this position. Quite often, though, it is necessary to weld in the overhead, vertical, or horizontal position in aircraft repair.

The flat position is used when the material can be laid flat, or inclined at an angle of less than 45° and welded on the topside. The welding torch is pointed downward toward the work. This weld may be made by either the forehand or backhand technique, depending upon the thickness of the metal being welded.

The horizontal position is used when the line of the weld runs horizontally across a piece of work, and the torch is directed at the material in a horizontal or nearly horizontal position. The weld is made from right to left across the plate (for the right-handed welder). The flame is inclined upward at an angle of from 45° to 60°. The weld can be made using the forehand or backhand technique. Adding the filler rod to the top of the puddle will help prevent the molten metal from sagging to the lower edge of the bead.

The overhead position is used when the material is to be welded on the underside with the seam running horizontally or in a plane that requires the flame to point upward from below the work. In welding overhead, a large pool of molten metal should be avoided, as the metal will drip or run out of the joint. The rod is used to control the size of the molten puddle. The volume of flame used should not exceed that required to obtain good fusion of the base metal with the filler rod. The amount of heat needed to make the weld is best controlled by selecting the right tip size for the thickness of metal to be welded.

When the parts to be joined are inclined at an angle of more than 45°, with the seam running vertically, it is designated as a vertical weld. In a vertical weld, the pressure exerted by the torch flame must be relied upon to a great extent to support the puddle. It is highly important to keep the puddle from becoming too hot, to prevent the hot metal from running out of the puddle onto the finished weld. Vertical welds are begun at the bottom, and the puddle is carried upward using the forehand technique. The tip should be inclined from 45° to 60°, the exact angle depending upon the desired balance between correct penetration and control of the puddle. The rod is added from the top and in front of the flame.

WELDED JOINTS

The five fundamental types of welded joints (figure 6–10) are the butt joint, tee joint, lap joint, corner joint, and edge joint.

Butt Joints

A butt joint is made by placing two pieces of material edge to edge, so that there is no overlapping, and then welded. Some of the various types of butt joints are shown in figure 6–11. The flanged butt joint can be used in welding thin sheets, $1/16$ in. or less. The edges are prepared for welding by turning up a flange equal to the thickness of the metal. This type of joint is usually made without the use of filler rod.

A plain butt joint is used for metals from $1/16$ in. to $1/8$ in. in thickness. A filler rod is used when making this joint to obtain a strong weld.

If the metal is thicker than $1/8$ in., it is necessary to bevel the edges so that the heat from the torch can penetrate completely through the metal. These

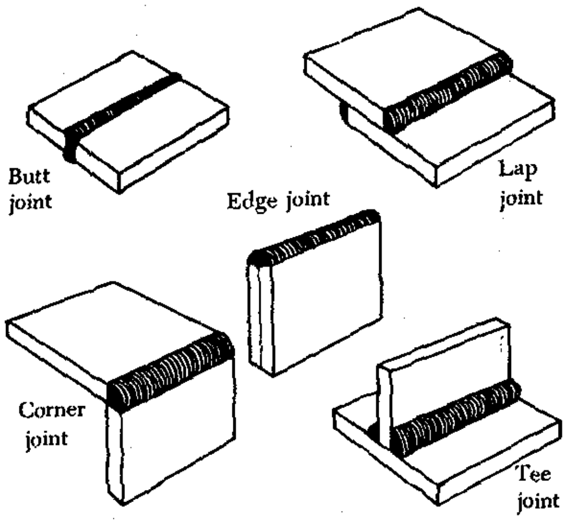


FIGURE 6–10. Basic welding joints.

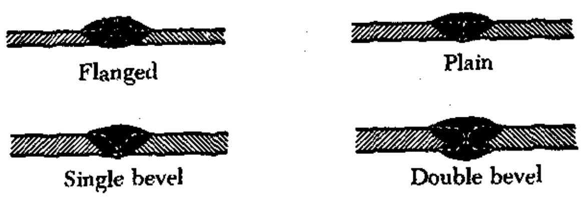


FIGURE 6–11. Types of butt joints.

bevels may be either single- or double-bevel type or single- or double-V type. A filler rod is used to add strength and reinforcement to the weld.

Cracks

Repair of cracks by welding may be considered just another type of butt joint. A stop drill hole is made at either end of the crack, then the two edges are brought together. The use of a filler rod is necessary.

Tee Joints

A tee joint is formed when the edge or end of one piece is welded to the surface of another, as shown in figure 6–12. These joints are quite common in aircraft work, particularly in tubular structures. The plain tee joint is suitable for most aircraft metal thicknesses, but heavier thicknesses require the vertical member to be either single or double beveled to permit the heat to penetrate deeply enough. The dark areas in figure 6–12 show the depth of heat penetration and fusion required.

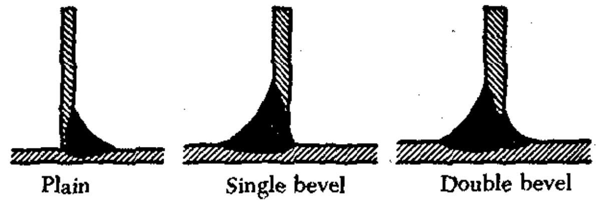


FIGURE 6–12. Types of tee joints.

Edge Joints

An edge joint may be used when two pieces of sheet metal must be fastened together and load stresses are not important. Edge joints are usually made by bending the edges of one or both parts upward, placing the two bent ends parallel to each other or placing one bent end parallel to the upright unbent end, and welding along the outside of the seam formed by the two joined edges. Figure 6–13 shows two types of edge joints. The type shown in fig. 6–13A requires no filler rod, since the edges can be melted down to fill theseam. The type shown in fig 6–13B, being thicker material, must be beveled for heat penetration; filler rod is added for reinforcement.

Corner Joints

A corner joint is made when two pieces of metal are brought together so that their edges form a corner of a box or enclosure as shown in figure 6–14. The corner joint shown in fig. 6–14A requires little or no filler rod, since the edges fuse to make the weld. It is used where load stress is unimportant. The joint shown in fig 6–14B is used on heavier metals, and filler rod is added for roundness and strength. If much stress is to be placed on

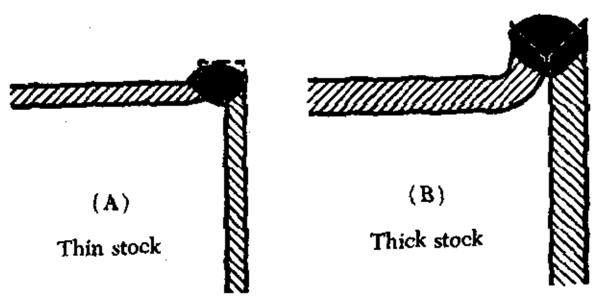


FIGURE 6–13. Edge joints.

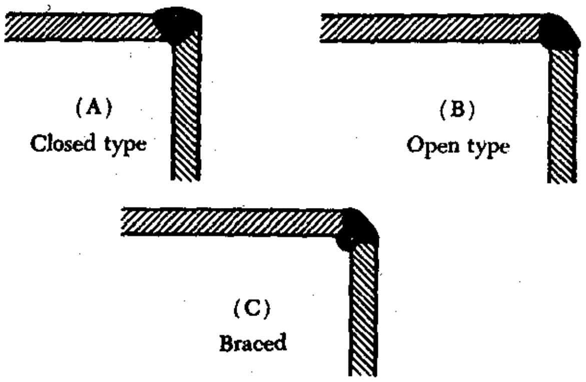


FIGURE 6–14. Corner joints.

the corner, the inside is reinforced as shown in fig. 6–14C.

Lap Joints

The lap joint is seldom used in aircraft structures when welding with oxyacetylene, but is commonly used when spot welding. The single lap joint (figure 6–15) has very little resistance to bending, and will not withstand the shearing stress to which the weld may be subjected under tension or compression loads. The double lap joint (figure 6–15) offers more strength, but requires twice the amount of welding required on the simpler, more efficient butt weld.

FIGURE 6–15. Single and double lap joints.

EXPANSION AND CONTRACTION OF METALS

Heat causes metals to expand; cooling causes them to contract. Uneven heating, therefore, will cause uneven expansion, or uneven cooling will cause uneven contraction. Under such conditions, stresses are set up within the metal. These forces must be relieved, and unless precautions are taken, warping or buckling of the metal will take place. Likewise, on cooling, if nothing is done to take up the stress set up by the contraction forces, further warping may result; or if the metal is too heavy to permit this change in shape, the stresses remain within the metal itself.

The coefficient of linear expansion of a metal is the amount in inches that a 1 in. piece of metal will expand when its temperature is raised 1° F. The amount that a piece of metal will expand when heat is applied is found by multiplying the coefficient of linear expansion by the temperature rise, and that product by the length of the metal in inches. For example, if a 10 ft. aluminum rod is to be raised to a temperature of 1,200° F. from a room temperature of 60° F., the rod will expand 1.75 in.—0.00001280 (aluminum's coefficient of linear expansion) X 120 (length in inches) X 1140 (temperature rise).

Expansion and contraction have a tendency to buckle and warp thin sheet metal $\frac{1}{8}$ in. or thinner. This is the result of having a large surface area that spreads heat rapidly and dissipates it soon after the source of heat is removed. The most effective method of alleviating this situation is to remove the heat from the metal near the weld, and thus prevent it from spreading across the whole surface area. This can be done by placing heavy pieces of metal, known as "chill bars," on either side of the weld; they absorb the heat and prevent it from spreading. Copper is most ofen used for chill bars because of its ability to absorb heat readily. Welding jigs sometimes use this same principle to remove heat from the base metal.

Expansion can also be controlled by tack welding at intervals along the joint.

The effect of welding a long seam (over 10 or 12 in.) is to draw the seam together as the weld progresses. If the edges of the seam are placed in contact with each other throughout their length before welding starts, the far ends of the seam will actually overlap before the weld is completed. This tendency can be overcome by setting the pieces to be welded with the seam spaced correctly at one end and increasing the space at the opposite end as shown in figure 6–16. The amount of space depends on the type of material, the thickness of the material, the welding process being used, and the shape and size of the pieces to be welded.

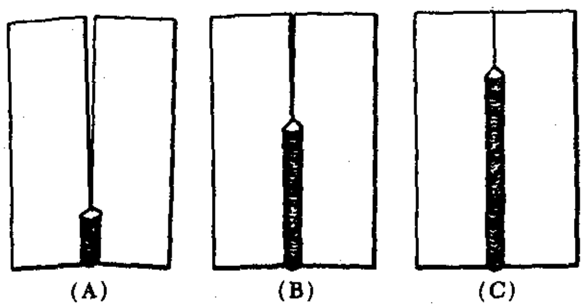


FIGURE 6–16. Allowance for a straight butt weld when welding steel sheets.

The weld is started at the correctly spaced end and proceeds toward the end that has the increased gap. As the seam is welded, the space will close and should provide the correct gap at the point of welding. Sheet metal under $\frac{1}{16}$ in. can be handled by flanging the edges, tack welding at intervals, and then by welding between the tacks.

There is less tendency for plate stock over $\frac{1}{8}$ in. to warp and buckle when welded because the greater thickness limits the heat to a narrow area and dissipates it before it travels far on the plate.

Preheating the metal before welding is another method of controlling expansion and contraction. Preheating is especially important when welding tubular structures and castings. Great stress can be set up in tubular welds by contraction. When two members of a tee joint are welded, one tube tends to draw up because of the uneven contraction. If the metal is preheated before the welding operation begins, contraction still takes place in the weld, but the accompanying contraction in the rest of the structure is at almost the same rate, and internal stress is lessened.

CORRECT FORMING OF A WELD

The form of the weld metal has considerable bearing upon the strength and fatigue resistance of a joint. The strength of an improperly made weld is usually less than the strength for which the joint was designed. Low-strength welds are generally the result of insufficient penetration; undercutting of the base metal at the toe of the weld; poor fusion of the weld metal with the base metal; trapped oxides, slag, or gas pockets in the weld; overlap of the weld metal on the base metal; too much or too little reinforcement; and overheating of the weld.

Characteristics of a Good Weld

A completed weld should have the following characteristics:

(1) The seam should be smooth, the bead ripples evenly spaced, and of a uniform thickness.
(2) The weld should be built up, thus providing extra thickness at the joint.
(3) The weld should taper off smoothly into the base metal.
(4) No oxide should be formed on the base metal close to the weld.
(5) The weld should show no signs of blowholes, porosity, or projecting globules.
(6) The base metal should show no signs of burns, pits, cracks, or distortion.

Although a clean, smooth weld is desirable, this characteristic does not necessarily mean that the weld is a good one; it may be dangerously weak inside. However, when a weld is rough, uneven, and pitted, it is almost always unsatisfactory inside. Welds should never be filed to give them a better appearance, since filing deprives the weld of part of its strength. Welds should never be filled with solder, brazing material, or filler of any sort. Additional information about weld characteristics is contained in Chapter 10, of the Airframe and Powerplant Mechanics General Handbook, AC 65–9A.

When it is necessary to re-weld a joint, all old weld material must be removed before the operation is begun. It must be remembered, though, that reheating the area may cause the base metal to lose some of its strength and become brittle.

OXYACETYLENE WELDING OF FERROUS METALS

Steel

Low-carbon steel, low-alloy steel, cast steel, and wrought iron are easily welded with the oxyacetylene flame. Plain, low-carbon steel is the ferrous material that will be gas welded most frequently. As the carbon content of steel increases, it may be repaired by welding only under certain conditions. Factors involved are carbon content and hardenability. For corrosion- and heat-resistant nickel chromium steels, the allowed weldability depends upon their stability, carbon content, or re-heat treatment.

In order to make a good weld, the carbon content of the steel must not be altered, nor can other chemical constitutents be added to or subtracted from the base metal without seriously altering the properties of the metal. Molten steel has a great affinity for carbon, and oxygen and nitrogen combine with the molten puddle to form oxides and nitrates, both of which lower the strength of steel. When welding with an oxyacetylene flame, the inclusion of impurities can be minimized by observing the following precautions:

(1) Maintain an exact neutral flame for most steels, and a slight excess of acetylene when welding alloys with a high nickel or chromium content, such as stainless steel.
(2) Maintain a soft flame and control the puddle.
(3) Maintain a flame sufficient to penetrate the metal and manipulate it so that the molten metal is protected from the air by the outer envelope of flame.
(4) Keep the hot end of the welding rod in

the weld pool or within the flame envelope.

Proper preparation for welding is an important factor in every welding operation. The edges of the parts must be prepared in accordance with the joint design chosen. The method chosen (bevel, groove, etc.) should allow for complete penetration of the base metal by the flame. The edges must be clean. Arrangements must be made for preheating, if this is required.

When preparing an aircraft part for welding, remove all dirt, grease or oil, and any protective coating such as cadmium plating, enamel, paint, or varnish. Such coatings not only hamper welding, but also mingle with the weld and prevent good fusion.

Cadmium plating can be chemically removed by dipping the edges to be welded in a mixture of 1 lb. of ammonium nitrate and 1 gal. of water.

Enamel, paint, or varnish may be removed from steel parts by a number of methods, such as a steel wire brush or emery cloth, by gritblasting, by using paint or varnish remover, or by treating the pieces with a hot, 10% caustic soda solution followed by a thorough washing with hot water to remove the solvent and residue. Gritblasting is the most effective method for removing rust or scale from steel parts. Grease or oil may be removed with a suitable grease solvent.

Enamel, paint, varnish, or heavy films of oxide on aluminum alloys can be removed using a hot 10% solution of either caustic soda or tri-sodium phosphate. After treatment, the parts should be immersed in a 10% nitric acid solution, followed with a hot water rinse to remove all traces of the chemicals. Paint and varnish can also be removed using paint and varnish remover.

The tip of the filler rod should be dipped below the surface of the weld puddle with a motion exactly opposite the motion of the torch. If the filler rod is held above the surface of the puddle, it will melt and fall into the puddle a drop at a time, ruining the weld.

Filler metal should be added until the surface of the joint is built up slightly above the edges of the parts being joined. The puddle of molten metal should be gradually advanced along the seam until the end of the material is reached.

As the end of the seam is approached, the torch should be raised slightly, chilling the molten steel to prevent it from spilling over the edge or melting through the work.

Chrome Molybdenum

The welding technique for chrome molybdenum is practically the same as that for carbon steels, except that the surrounding area must be preheated to a temperature between 300° and 400° F. before beginning to weld. If this is not done, the sudden application of heat causes cracks to form in the heated area.

A soft neutral flame should be used for welding; an oxidizing flame may cause the weld to crack when it cools, and a carburizing flame will make the metal brittle. The volume of the flame must be sufficient to melt the base metal, but not so hot as to weaken the grain structure of the surrounding area and set up strains in the metal. The filler rod should be the same as the base metal. If the weld requires high strength, a special chrome molybdenum rod is used and the piece is heat treated after welding.

Chrome molybdenum thicker than 0.093 in. is usually electric-arc welded, since for this thickness of metal, electric arc provides a narrow heat zone, fewer strains are developed, and a better weld is obtained, particularly when the part cannot be heat treated after welding.

Stainless Steel

The procedure for welding stainless steel is basically the same as that for carbon steels. There are, however, some special precautions that must be taken to obtain the best results.

Only stainless steel used for nonstructural members of aircraft can be welded satisfactorily; the stainless steel used for structural components is cold worked or cold rolled and, if heated, loses some of its strength. Nonstructural stainless steel is obtained in sheet and tubing form and is often used for exhaust collectors, stacks or manifolds. Oxygen combines very readily with this metal in the molten state, and extreme care must be taken to prevent this from occurring.

A slightly carburizing flame is recommended for welding stainless steel. The flame should be adjusted so that a feather of excess acetylene, about $\frac{1}{16}$ in. long, forms around the inner cone. Too much acetylene, however, will add carbon to the metal and cause it to lose its resistance to corrosion. The torch tip size should be one or two sizes smaller than that prescribed for a similar gage of low carbon steel. The smaller tip lessens the chances of overheating and subsequent loss of the corrosion-resistant qualities of the metal.

To prevent the formation of chromium oxide, a flux should be spread on the underside of the joint and on the filler rod. Since oxidation is to be avoided as much as possible, sufficient flux should be used. Another method used to keep oxygen from reaching the metal is to surround the weld with a blanket of hydrogen gas. This method is discussed later. The filler rod used should be of the same composition as the base metal.

Since the coefficient of expansion of stainless steel is high, thin sheets which are to be butt-welded should be tacked at intervals of 1-¼ to 1-½ inches, as shown in figure 6–17. This is one means of lessening warping and distortion during the welding process.

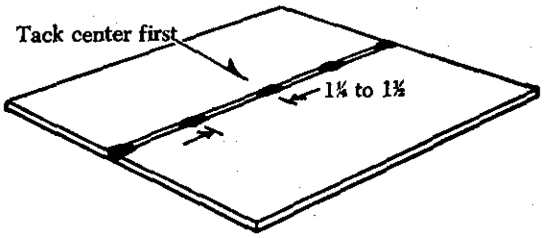


FIGURE 6–17. Tacking method for stainless steel welding.

When welding, hold the filler rod within the envelope of the torch flame so that the rod is melted in place or melted at the same time as the base metal. Add the filler rod by allowing it to flow into the molten pool. If the weld pool is stirred, air will enter the weld and increase oxidation. Avoid rewelding any portion or welding on the reverse side of the weld. Such practices result in warping and overheating of the metal.

WELDING NONFERROUS METALS USING OXY-ACETYLENE

Nonferrous metals are those that contain no iron. Examples of nonferrous metals are lead, copper, silver, magnesium, and most important in aircraft construction, aluminum. Some of these metals are lighter than the ferrous metals, but in most cases they are not as strong. Aluminum manufacturers have compensated for the lack of strength of pure aluminum by alloying it with other metals or by cold working it. For still greater strength, some aluminum alloys are also heat treated.

Aluminum Welding

The weldable aluminum alloys used in aircraft construction are 1100, 3003, 4043, and 5052. Alloy numbers 6053, 6061, and 6151 can also be welded, but since these alloys are in the heat-treated condition, welding should not be done unless the parts can be re-heat treated.

The equipment and technique used for aluminum welding differ only slightly from those of methods discussed earlier. As in all welding, the first step is to clean the surface to be welded—steel wool or a wire brush may be used, or a solvent in the case of paint or grease. The welder should be careful not to scratch the surface of the metal beyond the area to be welded; these scratches provide entry points for corrosion. The piece should then be preheated to lessen the strains caused by the large coefficient of expansion of aluminum.

Never preheat aluminum alloys to a temperature higher than 800° F. because the heat may melt some of the alloys and burn the metal. For thin sheet aluminum, merely passing the flame back and forth across the sheet three or four times should be sufficient.

Either of two types of filler rod can be used in welding aluminum alloys. Choosing the proper filler rod is important.

Aluminum and its alloys combine with air and form oxides very rapidly; oxides form doubly fast if the metal is hot. For this reason it is important to use a flux that will minimize or prevent oxides from forming.

Using the proper flux in welding aluminum is extremely important. Aluminum welding flux is designed to remove the aluminum oxide by chemically combining with it. Aluminum fluxes dissolve below the surface of the puddle and float the oxides to the top of the weld where they can be skimmed off. The flux can be painted directly on the top and bottom of the joint if no filler rod is required; if filler rod is used, it can be coated, and if the pieces to be welded are thick, both the metal and the rod should be coated with flux.

After welding is finished, it is important that all traces of flux be removed by using a brush and hot water. If aluminum flux is left on the weld, it will corrode the metal. A diluted solution of 10% sulfuric acid may be used if hot water is not available. The acid solution should be washed off with cold water.

Thickness of the aluminum alloy material determines the method of edge preparation. On material up to 0.062 in., the edges are usually formed to a 90° flange about the same height as the thickness of the material (figure 6–18A). The flanges should be straight and square. No filler rod is necessary when the edges are flanged in this manner.

Unbeveled butt welds are usually made on aluminum alloy from 0.062 to 0.188 in. thick. It may also be necessary to notch the edges with a saw or cold chisel in a manner similar to that shown in figure 6–18B. Edge notching is recommended in aluminum welding because it aids in getting full penetration and also prevents local distortion. All butt welds in material over 0.125 in. thick are generally notched in some manner.

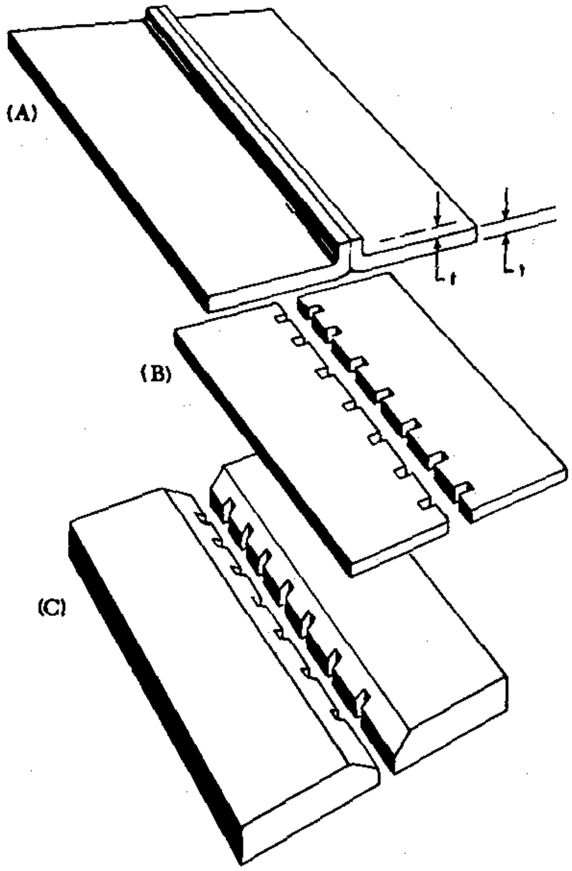


FIGURE 6–18. Edge preparation for welding aluminum.

In welding aluminum over 0.188 in. thick, the edges are usually beveled and notched as shown in figure 6–18C. The included angle of bevel may be from 90° to 120°.

A neutral flame should generally be used to weld aluminum alloys. In some cases a slightly carburizing flame can be used. However, the excess of acetylene should not be too great, as it will be absorbed into the molten metal, resulting in a weakened joint.

The torch must be adjusted to give the mildest flame that can be obtained without popping. The use of a strong, harsh flame makes it difficult to control the melting metal, and holes are often burned through the metal.

When starting to weld, the two joint edges should begin to melt before the filler rod is added. The work must be watched carefully for signs of melting. The melting point of aluminum is low and heat is conducted rapidly through the material. There is very little physical or color change to indicate that the metal is reaching the melting point. When the melting point is reached, the metal suddenly collapses and runs, leaving a hole in the aluminum.

A filler rod can be used to test the metal's condition. Aluminum begins to feel soft and plastic just before it reaches the melting point. Any tendency of the metal to collapse can be rectified by rapidly lifting the flame clear of the metal. With practice it is possible to develop enough skill to melt the metal surface without forming a hole.

The flame should be neutral and slanted at an approximate 45° angle to the metal. The inner cone should be about ⅛ in. from the metal. A constant and uniform movement of the torch is necessary to prevent burning a hole through the metal.

The correct integration of torch and rod action is important when welding aluminum. After heating the metal and when melting has begun, the filler rod is dipped into the pool and allowed to melt. The filler rod is lifted and the torch movement continues as the weld progresses. The rod is never lifted out of the outer envelope of flame, but is held there until almost melted and then added to the pool.

Magnesium Welding

Many aircraft parts are constructed of magnesium because of its light weight, strength, and excellent machinability. This metal is only two-thirds as heavy as aluminum and, like aluminum, is very soft in its pure state. For this reason, it is generally alloyed with zinc, manganese, tin, aluminum, or combinations of these metals. Repair of magnesium by welding is limited by two factors:

(1) If the magnesium is used as a structural member, it is usually heat treated and, like heat-treated aluminum, the welded section can never have the strength of the original metal. (As a rule, failures do not occur in the welded area, but in the areas adjacent to the weld, because the heat applied to

the metal weakens the grain structure in those areas.)

(2) It is necessary to use flux in making all magnesium welds, and to remove all the flux from the metal after welding or severe corrosion will take place.

The type of joint is limited to those that provide no possibility of trapping the flux—therefore, only butt welds can be made. Magnesium cannot be welded to other metals, and magnesium alloy castings are not considered suitable for stressed welds. If varying thicknesses of magnesium are to be welded, the thicker part must be preheated. The filler rod should be of the same composition as the base metal and one prepared by the manufacturer to fuse with his alloy. The filler rod comes with a protective plating that must be cleaned off before using.

The method of preparing the butt joint depends on the thickness of the metal. Sheet magnesium alloy up to 0.040 in. thick should be flanged by about 3/32 in. to the angle as indicated in figure 6–19. Butt joints on metal from 0.040 to 0.125 in. thick are neither flanged nor beveled, but a 1/16-in. space should be allowed between the edges of the joint. For butt joints in metal thicker than 0.125 in., each edge should be beveled down 45° to make a 90° included angle for the "V." A 1/16-in. space should be allowed between the edges of the joint for metal 0.125 to 0.250 in. thick and a 1/8-in. space for metal 0.250 in. and up (figure 6–19).

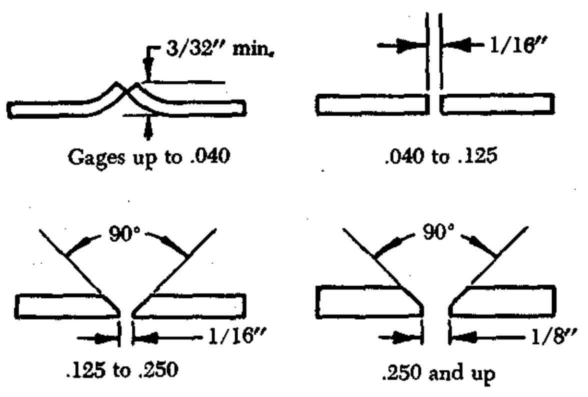


FIGURE 6–19. Preparation of edges for welding magnesium sheet.

Remove oil or grease with a suitable solvent, and then use a wire brush or abrasive cloth to clean and brighten the metal for a distance of 3/4 in. back from the weld area. Select a filler rod of the same material as the base metal. The filler rod and both sides of the seam should be covered with flux. Use a neutral or slightly carburizing flame, and hold it at a flat angle to the work to avoid burning through.

Two rod techniques are recommended for the welding of magnesium. One method requires that the filler rod be kept in the puddle at all times; the other method is the same as that used in welding aluminum.

It is preferable to make the weld on one uninterrupted pass, but if oxidation occurs, the weld should be stopped and scraped out before continuing. The joint edges should be tack-welded at the ends at intervals of 1/2 to 3 in., depending upon the shape and thickness of the metal.

Welding should be accomplished as quickly and with as little heat as possible. Buckling and warping can be straightened while the metal is still hot by hammering with a soft-faced mallet. The metal should be allowed to cool slowly. When the weld is cool enough to handle, the accessible portions should be scrubbed lightly, using a bristle brush and hot water, to remove excess flux. The part should then be soaked in hot water (160° to 200° F.) to float off the flux adhering to any portions not reached by the scrub brush. When soaking is completed, the part should be immersed in a 1% solution of citric acid for approximately 10 min.

After the citric acid bath the part should be drained thoroughly and then rinsed clean in fresh water. The part must be dried quickly and completely to prevent oxidation.

TITANIUM

Titanium welding does not have the wide application which steel has, therefore this handbook will not treat titanium as extensively.

Titanium Welding

Titanium can be fusion welded with weld efficiencies of 100% by arc welding techniques which, in many respects, are quite similar to those used for other metals.

Certain characteristics must be understood in order to successfully weld titanium.

1. Titanium and its alloys are subject to severe embrittlement by relatively small amounts of certain impurities. Oxygen and nitrogen even in quantities as low as 0.5% will embrittle a weld so much that it is useless.

Titanium, as it is heated toward its melting point will absorb oxygen and nitrogen from the atmosphere. In order to successfully weld titanium, the weld zone must be shielded with an inert gas such as argon or helium.

2. Cleanliness is necessary as titanium is very reactive with most materials. The metal and the welding area must be clean and free of dust, grease, and other contaminants. Contact with ceramic blocks and other foreign materials must be avoided during welding. Coated arc-welding electrodes, and other fluxing compounds will cause contamination and embrittlement.

3. Titanium, when alloyed excessively with other structural metals, looses ductility and impact strength due to the formation of brittle intermetallic compounds and excessive solid solution hardening.

4. Any fusion welding cycle results in a weld zone containing "as-cast material". Additionally, the high heat will have reduced the ductilities of certain highly heat-treatable titanium alloys to an unacceptable condition.

Equipment

Either non-consumable electrode or consumable electrode arc welding equipment may be used for fusion welding of titanium. Whatever type is used the weld must be shielded with an inert gas such as argon or helium.

Titanium may be spot welded with any machine which has accurate control over the four basic spot welding parameters: welding current amperage, duration of welding current (cycles at 60 cycles per second), force applied to the welding electrodes (pounds per square inch), and electrode geometry.

The complexity of titanium welding processes and its limited application outside of specialized titanium fabrication shops does not justify detailed treatment in this handbook.

The foregoing discussion on titanium welding was extracted from Titanium Welding Techniques, published by Titanium Metals Corporation of America.

CUTTING METAL USING OXYACETYLENE

Cutting metals by the oxyacetylene process is fundamentally the rapid burning or oxidizing of the metal in a localized area. The metal is heated to a bright red (1,400° to 1,600° F.), which is the kindling or ignition temperature, and a jet of high-pressure oxygen is directed against it. This oxygen blast combines with the hot metal and forms an intensely hot oxide. The molten oxide is blown down the sides of the cut, heating the metal in its path to a kindling temperature. The metal thus heated also burns to an oxide which is blown away on the underside of the piece. The action is precisely that which the torch accomplishes when the mixing head is replaced with a cutting attachment or when a special cutting torch is used.

Figure 6–20 shows an example of a cutting torch. It has the conventional oxygen and acetylene needle valves, which control the flow of the two gases. Many cutting torches have two oxygen needle valves so that a finer adjustment of the neutral flame can be obtained.

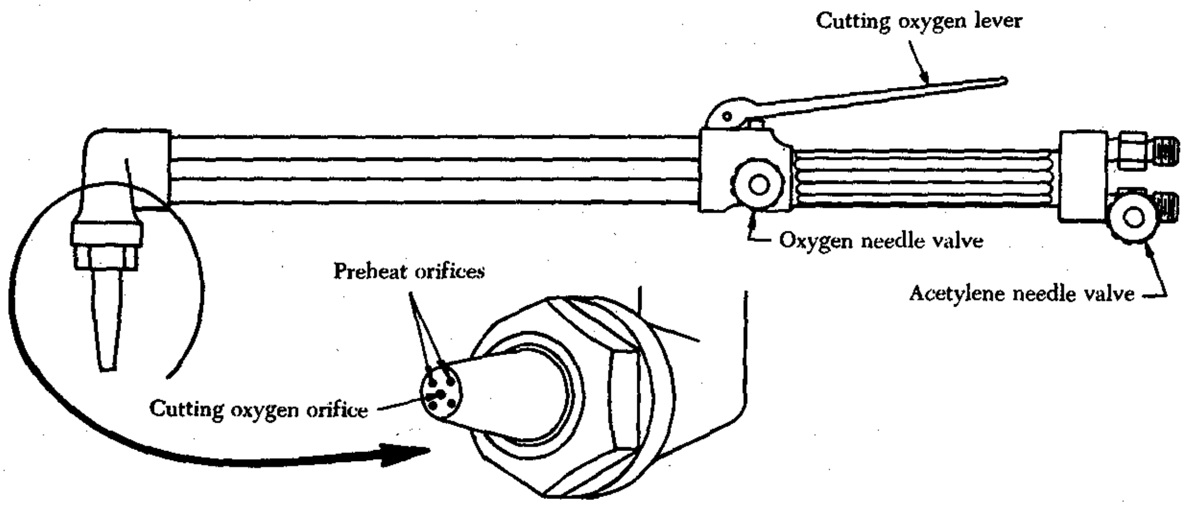


Figure 6–20. Cutting torch.

BRAZING METHODS

Brazing refers to a group of metal-joining processes in which the bonding material is a nonferrous metal or alloy with a melting point higher than 800° F., but is lower than that of the metals being joined. Brazing includes silver soldering, also called hard soldering, copper brazing, and aluminum brazing.

Brazing requires less heat than welding and can be used to join metals that are damaged by high heat. However, because the strength of brazed joints is not so great as welded joints, brazing is not used for structural repairs on aircraft. In deciding whether brazing of a joint is justified, it should be remembered that a metal which will be subjected to a sustained high temperature in use should not be brazed.

As the definition of brazing implies, the base metal parts are not melted. The brazing metal adheres to the base metal by molecular attraction and intergranular penetration; it does not fuse and amalgamate with them.

In brazing, the edges of the pieces to be joined are usually beveled as in welding steel. The surrounding surfaces must be cleaned of dirt and rust. Parts to be brazed must be securely fastened together to prevent any relative movement. The strongest brazed joint is one in which the molten filler metal is drawn in by capillary action, thus a close fit must be obtained.

A brazing flux is necessary to obtain a good union between the base metal and the filler metal. A good flux for brazing steel is a mixture containing two parts borax and one part boric acid. Application of the flux may be made in the powder form or dissolved in hot water to a highly saturated solution. A neutral torch flame should be used, moved with a slight semicircular motion.

The base metal should be preheated slowly with a mild flame. When it reaches a dull red heat (in the case of steel), the rod should be heated to a dark or purple color and dipped into the flux. Since enough flux adheres to the rod, it is not necessary to spread it over the surface of the metal.

A neutral flame is used for most brazing applications. However, a slightly oxidizing flame should be used when copper/zinc, copper/zinc/silicon, or copper/zinc/nickel/silicon filler alloys are used. When brazing aluminum and its alloys a neutral flame is preferred, but if difficulties are encountered, a slightly reducing flame is preferred to an oxidizing flame.

The filler rod can now be brought near the tip of the torch, causing the molten bronze to flow over a small area of the seam. The base metal must be at the flowing temperature of the filler metal before it will flow into the joint. The brazing metal melts when applied to the steel and runs into the joint by capillary attraction. The rod should continue to be added as the brazing progresses, with a rhythmic dipping action so that the bead will be built to a uniform width and height. The job should be completed rapidly and with as few passes as possible of the rod and torch.

When the job is finished, the weld should be allowed to cool slowly. After cooling, remove the flux from the parts by immersing them for 30 minutes in a lye solution.

Silver Solder

The principal use of silver solder in aircraft work is in the fabrication of high-pressure oxygen lines and other parts which must withstand vibration and high temperatures. Silver solder is used extensively to join copper and its alloys, nickel and silver, as well as various combinations of these metals, and thin steel parts. Silver soldering produces joints of higher strength than those produced by other brazing processes.

It is necessary to use flux in all silver soldering operations because of the necessity for having the base metal chemically clean without the slightest film of oxide to prevent the silver solder from coming into intimate contact with the base metal.

The joint must be physically clean, which means it must be free of all dirt, grease, oil, and/or paint, and also chemically clean. After removing the dirt, grease, and/or paint, any oxide should be renoved by grinding or filing the piece until bright metal can be seen. During the soldering operation, the flux continues the process of keeping oxide away from the metal, and aids the flow of the solder.

In figure 6–21, three types of joints for silver soldering are shown. Flanged, lap, and edge joints, in which the metal may be formed to furnish a seam wider than the base metal thickness, furnish the type of joint which will bear up under all kinds of loads. If a lap joint is used, the amount of lap should be determined according to the strength needed in the joint. For strength equal to that of the base metal in the heated zone, the amount of lap should be four to six times the metal thickness for sheet metal and small-diameter tubing.

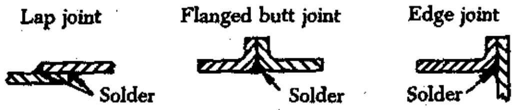


FIGURE 6–21. Silver soldering joints.

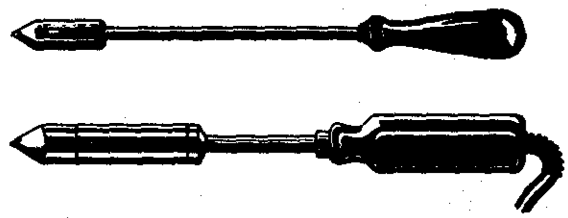


FIGURE 6–22. Soldering copper and soldering iron.

The oxyacetylene flame for silver soldering should be neutral, but may have a slight excess of acetylene. It must be soft, not harsh. During both preheating and application of the solder, the tip of the inner cone of the flame should be held about ½ in. from the work. The flame should be kept moving so that the metal will not become overheated.

When both parts of the base metal are at the right temperature (indicated by the flow of flux), solder can be applied to the surface of the under or inner part at the edge of the seam. It is necessary to simultaneously direct the flame over the seam and keep moving it so that the base metal remains at an even temperature.

SOFT SOLDERING

Soft soldering is used chiefly for copper, brass, and coated iron in combination with mechanical seams; that is, seams that are riveted, bolted, or folded. It is also used where a leakproof joint is desired, and sometimes for fitting joints to promote rigidity and prevent corrosion. Soft soldering is generally performed only in very minor repair jobs. This process is also used to join electrical connections. It forms a strong union with low electrical resistance.

Soft solder yields gradually under a steadily applied load and should not be used unless the transmitted loads are very low. It should never be used as a means of joining structural members.

A soldering copper (called a soldering iron if it is electrically heated) is the tool used in soldering. Its purpose is to act as a source of heat for the soldering operation. The bit, or working face, is made from copper, since this metal will readily take on heat and transmit it to the work. Figure 6–22 shows a correctly shaped bit.

To tin the copper, it is first heated to a bright red, then the point is cleaned by filing until it is smooth and bright. No dirt or pits should remain on its surface. After the copper has been mechanically cleaned, it should be re-heated sufficiently to melt solder, and chemically cleaned by rubbing it lightly on a block of sal ammoniac. (If sal ammoniac is not available, powdered resin may be used.) Then solder is applied to the point and wiped with a clean cloth.

The last two operations may be combined by melting a few drops of solder on a block of sal ammoniac (cleaning compound) and then rubbing the soldering copper over the block until the tip is well coated with solder. A properly tinned copper has a thin unbroken film of solder over the entire surface of its point.

Soft solders are chiefly alloys of tin and lead. The percentages of tin and lead vary considerably in various solders, with a corresponding change in their melting points, ranging from 293° to 592° F. "half-and-half" (50–50) solder is a general purpose solder and is most frequently used. It contains equal proportions of tin and lead and melts at approximately 360° F.

The application of the melted solder requires somewhat more care than is apparent. The parts should be locked together or held mechanically or manually while tacking. To tack the seam, the hot copper is touched to a bar of solder, then the drops of solder adhering to the copper are used to tack the seam at a number of points. The film of solder between the surfaces of a joint must be kept thin to make the strongest joint.

A hot, well-tinned soldering copper should be held so that its point lies flat on the metal at the seam, while the back of the copper extends over the seam proper at a 45° angle, and a bar of solder is touched to the point. As the solder melts, the copper is drawn slowly along the seam. As much solder as necessary is added without raising the soldering copper from the job. The melted solder should run between the surfaces of the two sheets and cover the full width of the seam. Work should progress along the seam only as fast as the solder will flow into the joint.

ELECTRIC ARC WELDING

Electric arc welding is a fusion process based on the principle of generating heat with an electric arc jumping an airgap to complete an electrical circuit. This process develops considerably more heat than an oxyacetylene flame. In some applications, it reaches a temperature of approximately 10,000° F. Variations of the process are metallic arc welding, inert-gas (helium) welding, and multi-arc welding. The metallic arc and helium processes have the widest application in aircraft maintenance.

The welding circuit (figure 6–23) consists of a welding machine, two leads, an electrode holder, an electrode, and the work to be welded. The electrode, which is held in electrode holder, is connected to one lead, and the work to be welded is connected to the other lead. When the electrode is touched to the metal to be welded, the electrical circuit is completed and the current flows. When the electrode is withdrawn from the metal, an airgap is formed between the metal and the electrode. If this gap is of the proper length, the electric current will bridge this gap to form a sustained electric spark, called the electric arc.

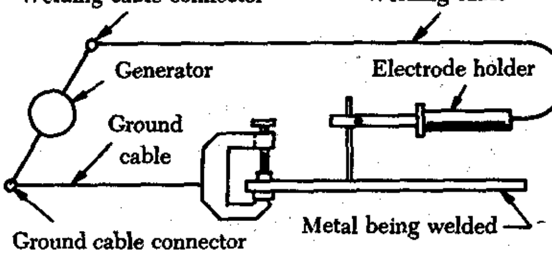


FIGURE 6–23. Typical arc-welding circuit.

Metallic Arc Welding

Metallic arc welding is used mainly for welding low-carbon and low-alloy steels. However, many nonferrous materials, such as aluminum and nickel alloys, can be welded using this method.

To form an arc between the electrode and the work, the electrode is applied to the work and immediately withdrawn. This initiates an arc of intense heat. To maintain the arc between the electrode and the work, the metal electrode must be fed at a uniform rate or maintained at a constant distance from the work as it melts.

Metallic arc welding is a nonpressure fusion welding process which develops welding heat through an arc produced between a metal electrode and the work to be welded. Under the intense heat developed by the arc, a small part of the base metal or work to be welded is brought to the melting point instantaneously. At the same time, the end of the metal electrode is also melted, and tiny globules or drops of molten metal pass through the arc to the base metal. The force of the arc carries the molten metal globules directly into the puddle formed on the base metal, and thus filler metal is added to the part being welded. By moving the metal electrode along the joint and down to the work, a controlled amount of filler metal can be deposited on the base metal to form a weld bead.

The instant the arc is formed, the temperature of the work at the point of welding and the welding electrode increases to approximately 6,500° F. This tremendous heat is concentrated at the point of welding and in the end of the electrode, and simultaneously melts the end of the electrode and a small part of the work to form a small pool of molten metal, commonly called the crater.

The heat developed is concentrated and causes less buckling and warping of work than gas welding. This localization of the heat is advantageous when welding cracks in heat-treated parts and when welding in close places.

Gas Shielded Arc-Welding

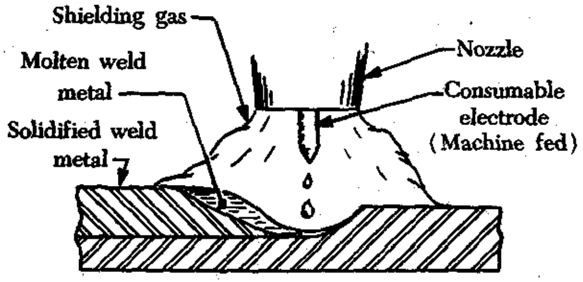
A good weld has the same qualities as the base metal. Such a weld has been made without the molten puddle being contaminated by atmospheric oxygen and/or nitrogen. In gas-shielded arc welding, a gas is used as a covering shield around the arc to prevent the atmosphere from contaminating the weld.

The original purpose of gas shielded arc welding was to weld corrosion resistant and other difficult-to-weld materials. Today the various gas shielded arc processes are being applied to all types of metal. See fig. 6–24 for typical applications.

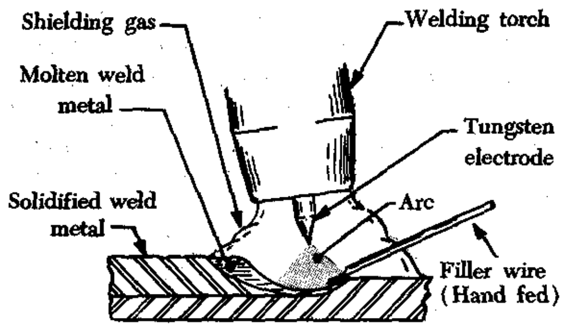
The ease of operation, increased welding speed and the superiority of the weld, will lead to shielded arc-welding and oxy-acetelyne welding being replaced with gas shielded arc welding.

Advantages of Gas-Shielded Arc Welding

The shielding gas excludes the atmosphere from the molten puddle. The resulting weld is stronger, more ductile and more corrosion resistant. Also welding of nonferrous metal does not require the use of flux. This eliminates flux removal, and the possibilities of gas pockets or slag inclusions.



Gas metal arc welding (MIG).



Gas tungsten – arc welding (TIG).

FIGURE 6-24A. Gas-shielded arc welding process.

Figures 6-24, 6-25, 6-26, and 6-27 courtesy Hobart Bros.

Another advantage of the gas shielded arc is that a neater and sounder weld can be made because there is very little smoke fumes or sparks to control. The weld may be observed at all times. Weld splatter is held to a minimum, therefore there is little or no metal finishing required. A gas-shielded weld does not distort the base metal near the weld. The completed weld is clean and free of the complications often encountered in other forms of metallic-arc or gas welding.

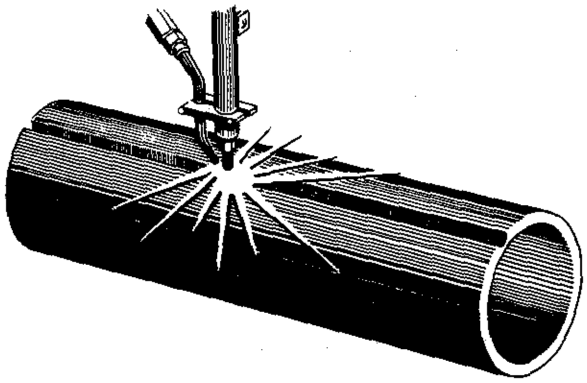


FIGURE 6-24(C). One of the many types of automatic welders.

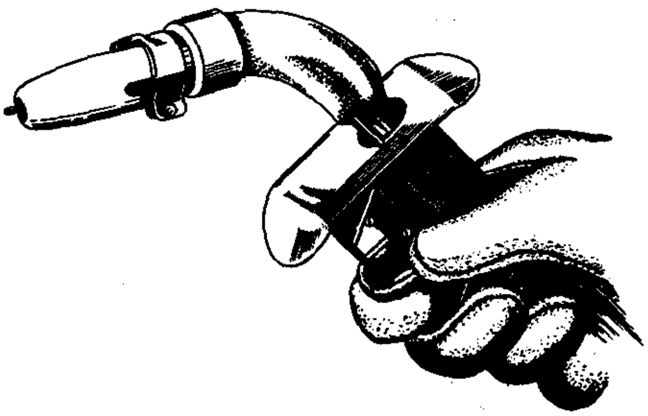


FIGURE 6-24(B). A semi-automatic welder.

Tungsten Inert Gas Welding (TIG)

In Tungsten Inert Gas (TIG) welding a virtually non-consumable tungsten electrode is used (figure 6-25) to provide the arc for welding. During the welding cycle a shield of inert gas expels the air from the welding area and prevents oxidation of the electrode, weld puddle and surrounding heat-affected zone. In TIG welding the electrode is used only to create the arc. If additional metal is needed, a filler rod is used in the same manner as in oxy-acetylene welding.

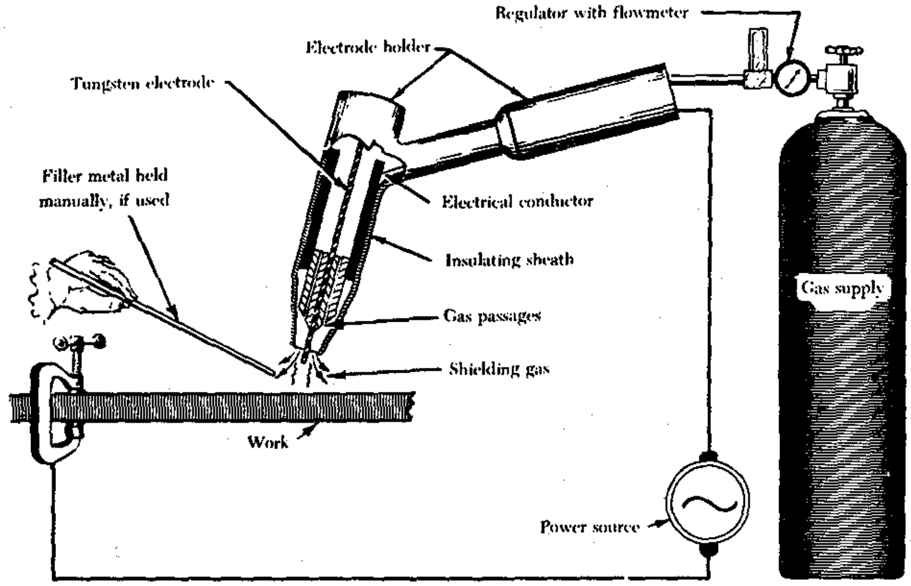


FIGURE 6–25. Typical TIG welding equipment.

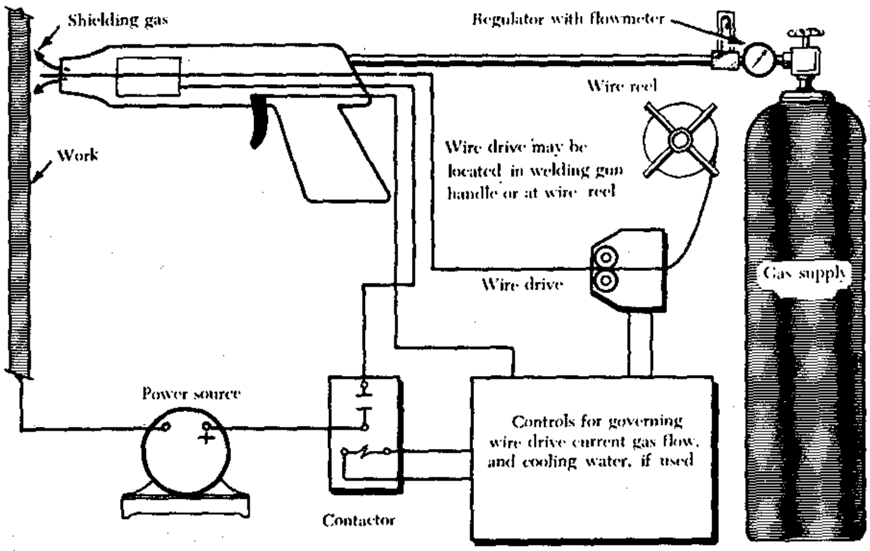


FIGURE 6–26. Typical MIG welding equipment.

The type gas used in TIG welding depends upon the metal being welded. Argon, helium or a mixture of the two gases is used. Argon is used more extensively than helium because it is cheaper. Argon is preferred for several reasons besides the cost. It is heavier therefore provides better cover. It provides better cleaning action when welding aluminum and magnesium. The welding arc is quieter and smoother. Vertical and overhead welding arcs are easier to control. Welding arcs are easier to start and for a given welding the weld produced is narrower with a smaller heat-affected zone.

Helium is used primarily in TIG machine welding or when welding heavy material having high heat conductivity. The arc voltage is higher when using helium, therefore a lower current flow is possible to get the same arc power.

Metal Inert Gas Arc Welding (MIG)

With the substitution of a continuous feed consumable wire electrode for the non-consumable tungsten electrode used in TIG, the welding process becomes Metal Inert Gas Arc Welding (figure 6–26). The wire electrode is fed continuously through the center of the torch at pre-set controlled speeds, shielding gas is fed through the torch, completely covering the weld puddle with a shield of gas. This tends to complete automation of the welding process. Power, gas flow, wire feed and travel over the work piece are preset when using a welding machine. In semi-automatic welding, the operator controls the travel over the work.

Argon is the commonly used gas. Some metals use small amounts of helium or oxygen. Low carbon steel uses carbon dioxide or argon plus 2% O_2.

Plasma Arc Welding

Plasma welding is a process which utilizes a central core of extreme temperature, surrounded by a sheath of coal gas. The required heat for fusion is generated by an electric arc which has been highly intensified by the injection of a gas into the arc stream.

The super-heated columnar arc is concentrated into a narrow stream and when directed on metal makes possible butt welds up to one-half inch in thickness or more in a single pass without filler rods or edge preparation.

In many respects plasma welding may be considered as an extension of the conventional TIG welding. In plasma arc welding the arc column is constricted and it is this constriction that produces the much higher heat transfer rate.

The arc plasma actually becomes a jet of high current density. The arc gas upon striking the metal cuts through the piece producing a small hole which is carried along the weld seam. During this cutting action, the melted metal in front of the arc flows around the arc column, then is drawn together immediately behind the hole by surface tension forces and reforms in a weld bead.

Plasma is often considered the fourth state of matter. The other three are gas, liquid, and solid. Plasma results when a gas is heated to a high temperature, and changes into positive ions, neutral atoms and negative electrons. When matter passes from one state to another latent heat is generated.

In a plasma torch the electrode is located within the nozzle. The nozzle has a relatively small orifice which constricts the arc. The high-pressure gas flows through the arc where it is heated to the plasma temperature range. Since the gas cannot expand due to the constriction of the nozzle, it is forced through the opening, and emerges in the form of a supersonic jet. This heat melts any known metal and its velocity blasts the molten metal through the kerf (figure 6–27).

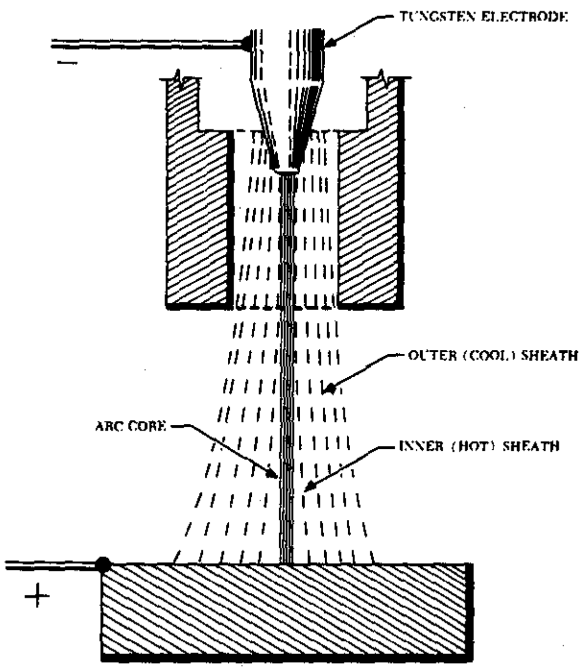


FIGURE 6-27. Plasma welding uses a centrol core of extreme temperature surrounded by a sheath of cool gas.

WELDING PROCEDURES AND TECHNIQUES

The first step in preparing to arc weld is to make certain that the necessary equipment is available and that the welding machine is properly connected and in good working order. Particular attention should be given to the ground connection, since a poor connection will result in a fluctuating arc, which is difficult to control.

The electrode should be clamped to its holder at right angles to the jaws. Shielded electrodes have one end of the electrode free of coating to provide

good electrical contact. The electrode holder should be handled with care to prevent accidental contact with the bench or work, since such contact may weld it fast.

Before starting to weld, the following typical list of items should be checked:

(1) Is the machine in good working order?

(2) Have all connections been properly made? Will the ground connection make good contact?

(3) Has the proper type and size electrode been selected for the job?

(4) Is the electrode properly secured in the holder?

(5) Has sufficient protective clothing been provided, and is it in good condition?

(6) Is the work metal clean?

(7) Does the polarity of the machine coincide with that of the electrode?

(8) Is the machine adjusted to provide the necessary current for striking the arc?

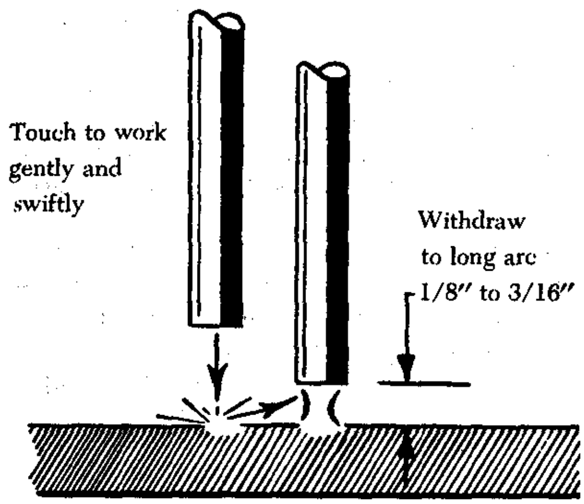


FIGURE 6–28. Touch method of starting the arc.

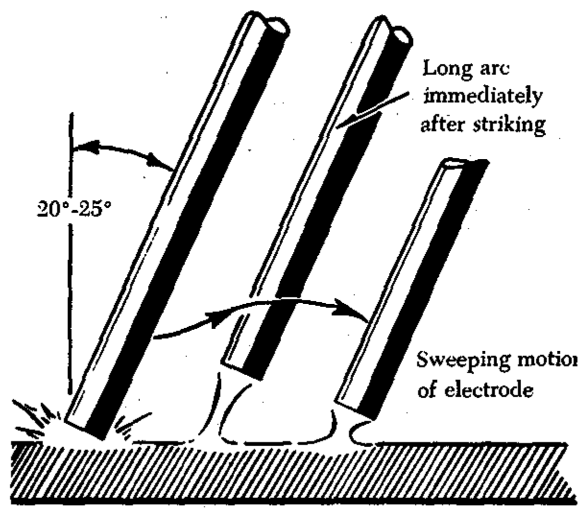


FIGURE 6–29. Scratch method of starting the arc.

The welding arc is established by touching the plate with the electrode and immediately withdrawing it a short distance. At the instant the electrode touches the plate, a rush of current flows through the point of contact. As the electrode is withdrawn, an electric arc is formed, melting a spot on the base metal and the end of the electrode.

The main difficulty confronting a beginner in striking the arc is freezing; that is, sticking or welding the electrode to the work. If the electrode is not withdrawn promptly upon contact with the plate, the high amperage will flow through the electrode and practically short circuit the welding machine. The heavy current melts the electrode which sticks to the plate before it can be withdrawn.

There are two essentially similar methods of striking the arc. The first is a touch method, illustrated in figure 6–28, and the second is a scratch method, shown in figure 6–29.

When using the touch method, the electrode should be held in a vertical position, and lowered until it is an inch or so above the point where the arc is to be struck. Then the electrode is touched very gently and swiftly to the work, using a downward motion of the wrist, followed immediately by withdrawing the electrode to form a long arc (approximately ⅛ to $\frac{3}{16}$ in. long).

To strike the arc by the scratch method, the electrode is moved downward until it is just above the plate and at an angle of 20° to 25°, as illustrated in figure 6–29. The arc should be struck gently, with a swiftly sweeping motion, scratching the electrode on the work with a wrist motion. The electrode is then immediately withdrawn to form a long arc. The purpose of holding an excessively long arc immediately after striking is to prevent the large drops of metal, passing across the arc at this time, from shorting out the arc and thus causing freezing.

To form a uniform bead, the electrode must be moved along the plate at a constant speed in addition to the downward feed of the electrode. The rate of advance, if too slow, will form a wide bead resulting in overlapping, with no fusion at the edges. If the rate of advance is too fast, the bead will be too narrow and have little or no fusion at the plate. When proper advance is made, no overlapping occurs, and good fusion is assured.

In advancing the electrode, it should be held at an angle of about 20° to 25° in the direction of travel, as illustrated in figure 6-30.

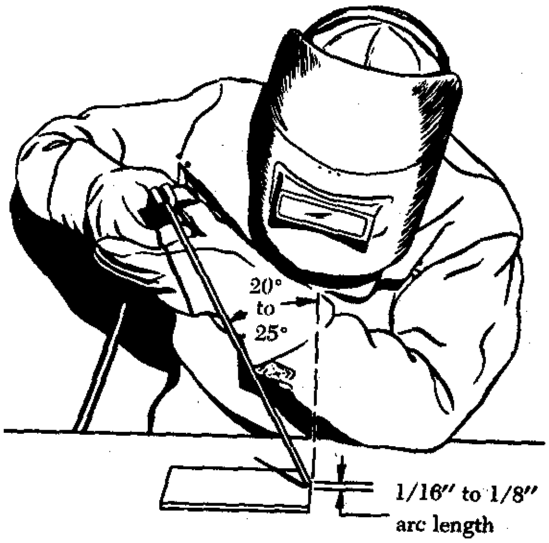


FIGURE 6-30. Angle of electrode.

If the arc is broken during the welding of a bead, a crater will be formed at the point where the arc ends. The arc may be broken by feeding the electrode too slowly or too fast, or when the electrode should be replaced. The arc should not be re-started in the crater of the interrupted bead, but just ahead of the crater on the work metal. Then, the electrode should be returned to the back edge of the crater. From this point, the weld may be continued by welding right through the crater and down the line of weld, as originally planned. Figure 6-31 illustrates the procedure for re-starting the arc.

Every particle of slag must be removed from the vicinity of the crater before re-starting the arc. This prevents the slag from becoming trapped in the weld.

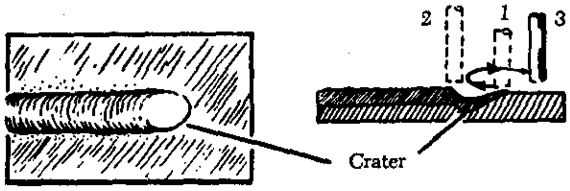


FIGURE 6-31. Re-starting the arc.

Multiple-Pass Welding

Groove and fillet welds in heavy metals often require the deposit of a number of beads to complete a weld. It is important that the beads be deposited in a predetermined sequence to produce the soundest welds with the best proportions. The number of beads is, of course, determined by the thickness of the metal being welded.

The sequence of the bead deposits is determined by the kind of joint and the position of the metal. All slag must be removed from each bead before another bead is deposited. Typical multiple-pass groove welding of butt joints is shown in figure 6-32.

Techniques of Position Welding

Each time the position of a welding joint or the type of joint is changed, it may be necessary to change any one or a combination of the following: (1) Current value, (2) electrode, (3) polarity, (4) arc length, or (5) welding technique.

Current values are determined by the electrode size as well as the welding position. Electrode size is governed by the thickness of the metal and the joint preparation, and the electrode type by the welding position. Manufacturers specify the polarity to be used with each electrode. Arc length is controlled by a combination of the electrode size, welding position, and welding current.

Since it is impractical to cite every possible variation occasioned by different welding conditions, only the information necessary for the commonly used positions and welds is discussed here.

Flat Position Welding

There are four types of welds commonly used in flat position welding. They are the bead, groove, fillet, and lap joint welds. Each type is discussed separately in the following paragraphs.

Bead Welds

Welding a square butt joint by means of stringer beads involves the same techniques as depositing

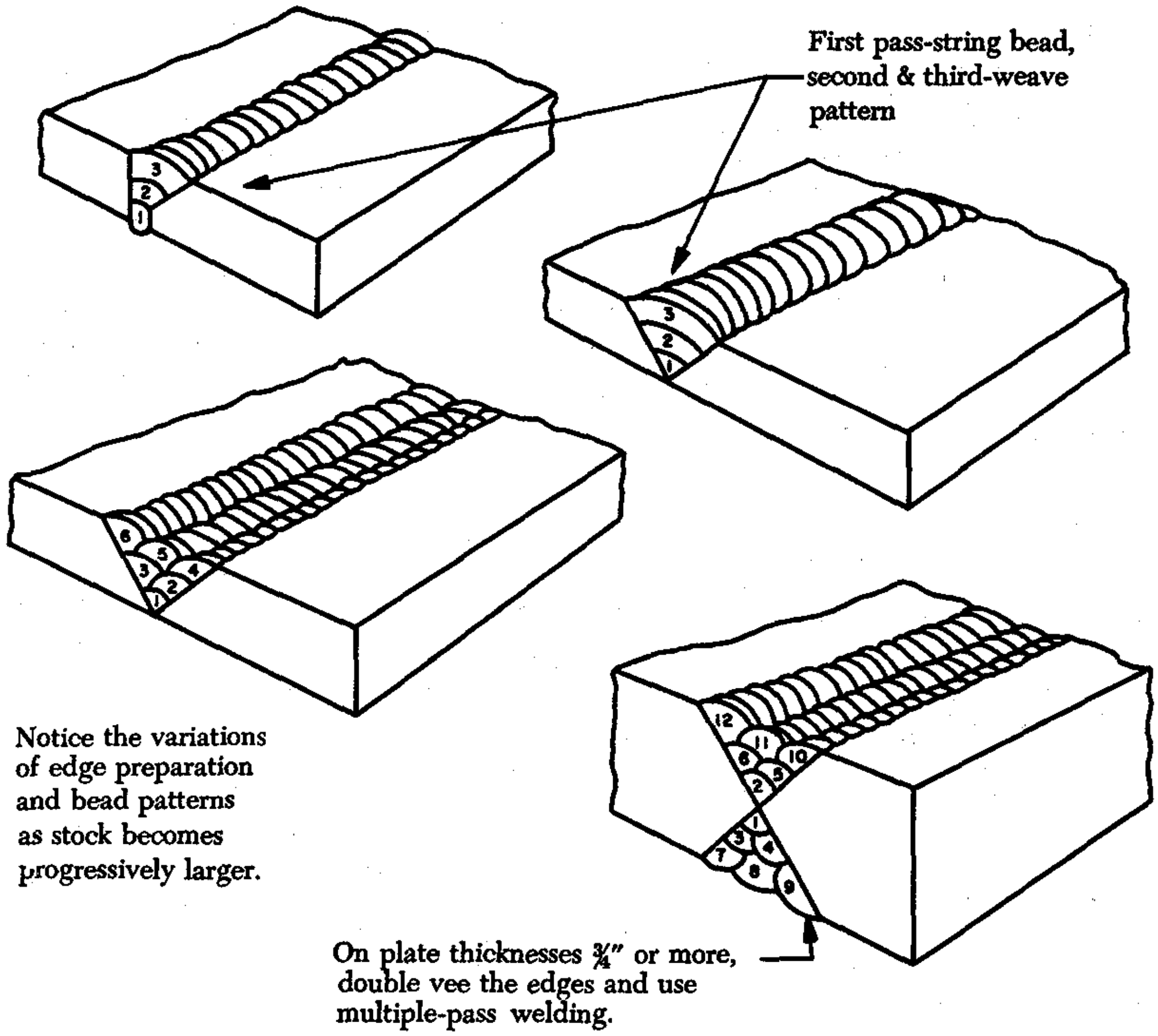


FIGURE 6–32. Multiple-pass groove welding of butt joints.

stringer beads on a flat metal surface. Square butt joints may be welded in one, two, or three pases. If the joint is welded with the deposition of one stringer bead, complete fusion is obtained by welding from one side. If the thickness of metal is such that complete fusion cannot be obtained by welding from one side, the joint must be welded from both sides.

When the metals to be welded are butted squarely together, two passes are necessary. If the metals must be spaced, three passes are required to complete the weld. In the latter case, the third pass is made directly over the first and completely envelops it.

It must be constantly kept in mind that beads, either the stringer or weave type, are used to weld all types of joints. Even though the bead may not be deposited on the same type of surface, its action in the different welding positions and joints is basically the same as its action on the surface of flat metal. The same fundamental rules apply regarding electrode size and manipulation, current values, polarity, and arc lengths.

Bead welds can be made by holding a short arc and welding in a straight line at a constant speed, with the electrode inclined 5° to 15° in the direction of welding. The proper arc can best be judged by recognizing a sharp cracking sound heard all during the time the electrode is being moved to and above the surface of the plate. Some of the characteristics of good bead welds are as follows:

(1) They should leave very little spatter on the surface of the plate.
(2) The arc crater, or depression, in the bead when the arc has been broken should be approximately $\frac{1}{16}$ in. deep.

(3) The depth of the crater at the end of the bead can be used as a measure of penetration into the base metal.

(4) The bead weld should be built up slightly, without any weld metal overlap at the top surface, which would indicate poor fusion.

Figure 6–33 illustrates a properly made bead weld.

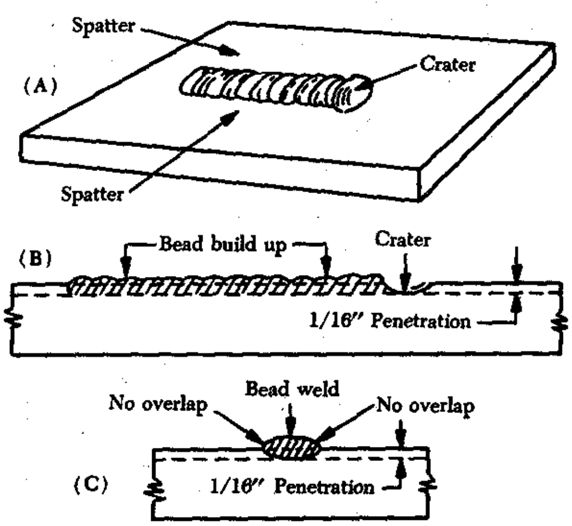


FIGURE 6–33. Properly made bead weld.

Groove Welds (Butt Joint)

Groove welding may be executed in either a butt joint or an outside corner joint. A outside corner joint corresponds to a single vee butt joint, and the same welding technique is used for both. For this reason, these two types of joints are classified under the heading of grooved welding. There are certain fundamentals which are applicable to groove welds, regardless of the position of the joint.

Groove welds are made on butt joints where the metal to be welded is ¼ in. or more in thickness. Butt joints with a metal thickness of less than ¼ in. require no special edge preparation and can be joined with a bead weld on one or both sides.

Groove welds can be classified as either single groove or double groove. This is true whether the shape of the groove is a V, U, J, or any other form. Regardless of the position in which a single-groove weld is made, it can be welded with or without a backing strip. If a backing strip is used, the joint may be welded from only one side. When a single-groove weld is made without a backing strip, the weld may be made from one side, if necessary, although welding from both sides assures better fusion.

The first pass of the weld deposit may be from either side of the groove. The first bead should be deposited to set the space between the two plates and to weld the root of the joint. This bead, or layer off weld metal, should be thoroughly cleaned to remove all slag before the second layer of metal is deposited. After the first layer is cleaned, each additional layer should be applied with a weaving motion, and each layer should be cleaned before the next one is applied.

The number of passes required to complete a weld is determined by the thickness of the metal being welded and the electrode size being used. As in bead welding, the tip of the electrode should be inclined between 5° and 15° in the direction of welding.

Double-groove welds are welded from both sides. This type of weld is used primarily on heavy metals to minimize distortion. This is best accomplished by alternately welding from each side; *i.e.*, depositing a bead from one side and then from the other. However, this necessitates turning the plates over several times (six times for ¾-in. plate.)

Distortion may be effectively controlled if the plates are turned over twice, as follows: (1) Weld half the passes on the first side; (2) turn the plate over and weld all the passes on the second side; and (3) turn the plates over and complete the passes on the first side.

The root of a double-groove weld should be made with a narrow bead, making sure that the bead is uniformly fused into each root face. When a few passes have been made on one side, the root on the opposite side should be chipped to sound metal to make the groove and then welded with a single-bead weld.

Any groove weld made in more than one pass must have the slag, spatter, and oxide carefully removed from all previous weld deposits before welding over them. Figure 6–34 shows some of the common types of groove welds performed on butt joints in the flat position.

Fillet Welds

Fillet welds are used to make tee and lap joints. In welding tee joints in the flat position, the two plates are placed to form an angle of 90° between their surfaces, as shown in figure 6–35. The electrode should be held at an angle of 45° to the plate surface. The top of the electrode should be tilted at an angle of about 15° in the direction of welding. Light plates should be welded with little or no

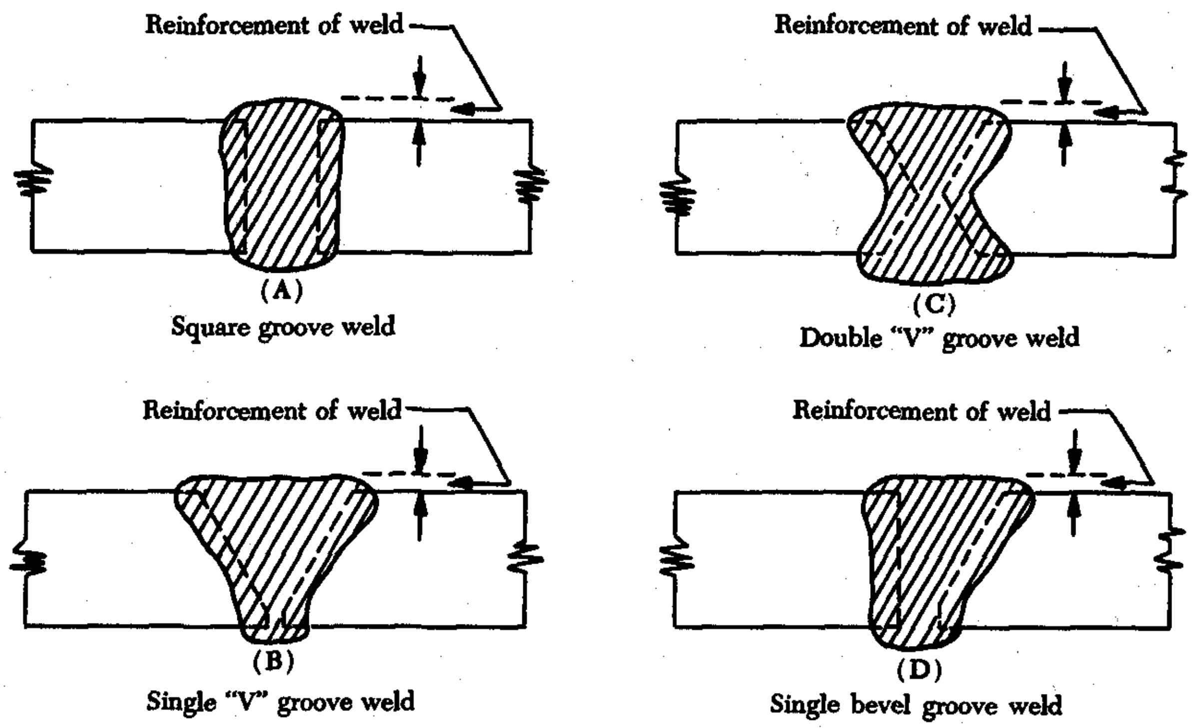


FIGURE 6–34. Groove welds on butt joints in the flat position.

weaving motion of the electrode, and the weld is made in one pass. Fillet welding of heavier plates may require two or more passes. In that case, the second pass or layer is made with a semicircular weaving motion. In making the weave bead, there should be a slight pause at the end of each weaving motion to obtain good fusion to the edges of the two plates without undercutting them.

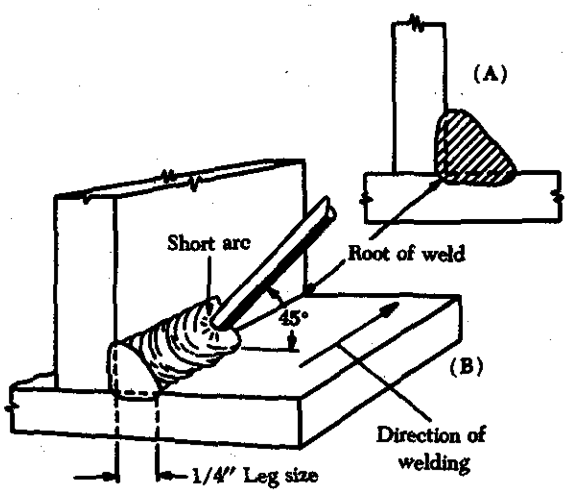


FIGURE 6–35. Tee joint fillet weld.

The procedure for making the lap joint fillet weld is similar to that used for making the fillet weld in a tee joint. The electrode should be held at an angle of 30° to the vertical. The top of the electrode should be tilted to an angle of 15° in the direction of welding. Figure 6–36 illustrates a typical lap joint. The weaving motion is the same as that used for tee joints, except that the hesitation at the edge of the top plate is prolonged to obtain good fusion with no undercut. When welding plates of different thickness, the electrode is held at an angle of 20° to the vertical. Care must be taken not to overheat and undercut the thinner plate edge. The arc must be controlled to wash up the molten metal to the edge of this plate.

Overhead Position Welding

The overhead position is one of the most difficult in welding, since a very short arc must be maintained constantly to retain complete control of the molten metal.

The force of gravity tends to cause the molten metal to drop down or sag on the plate. If a long arc is held, the difficulty in transferring metal from the electrode to the base metal is increased, and

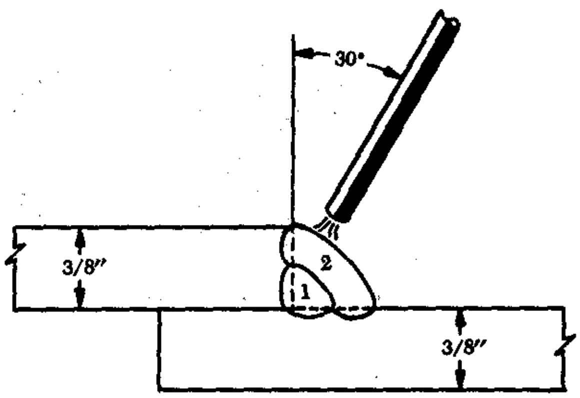


FIGURE 6–36. Typical lap joint fillet weld.

large globules of molten metal will drop from the electrode and the base metal. The transfer of metal is aided by first shortening and then lengthening the arc. However, care should be taken not to carry too large a pool of molten metal in the weld. The procedures for making bead, groove, and fillet welds in the overhead position are discussed in the following paragraphs.

Bead Welds

For bead welds, the electrode should be held at an angle of 90° to the base metal. In some cases, however, where it is desirable to observe the arc and the crater of the weld, the electrode may be held at an angle of 15° in the direction of welding. Weave beads can be made by using the weaving motion. A rather rapid motion is necessary at the end of each semicircular weave to control the molten metal deposit. Care should be taken to avoid excessive weaving. This will cause overheating of the weld deposit and form a large pool of metal, which is hard to control.

Groove Welds (Butt Joints)

Improved overhead groove welds can be made by using a backup strip. The plates should be prepared in a manner similar to preparing plates for welding butt joints in the flat position. If no backup strip is used and the plates are beveled with a featheredge, the weld will burn through repeatedly, unless the operator is extremely careful.

Fillet Welds

When making fillet welds on overhead tee or lap joints, a short arc should be held, and there should be no weaving of the electrode, The electrode should be held at an angle of about 30° to the vertical plate, and moved uniformly in the direction of welding.

The arc motion should be controlled to secure good penetration to the root of the weld and good fusion with the sidewalls of the vertical and horizontal plates. If the molten metal becomes too fluid and tends to sag, the electrode should be whipped away quickly from the crater ahead of the weld to lengthen the arc and allow the metal to solidify. The electrode should then be returned immediately to the crater of the weld and the welding continued.

Welding on heavy plates requires several passes to make the joint. The first pass is a string bead with no weaving motion of the electrode. The second, third, and fourth passes are made with a slight circular motion of the end of the electrode, while the top of the electrode is held tilted at an angle of about 15°.

Vertical Position Welding

The vertical position, like the overhead position just discussed, is also more difficult than welding in the flat position. Because of the force of gravity, the molten metal will always have a tendency to run down. To control the flow of molten metal, a short arc is necessary, as well as careful arc voltage and welding current adjustments.

In metallic arc welding, current settings for welds made in the vertical position should be less than those used for the same electrode size and type on welds made in the flat position. The currents used for welding upward on vertical plate are slightly lower than those used for welding downward on vertical plate. The procedure for making bead, groove, and fillet welds in the vertical position are discussed in the following paragraphs.

Bead Welds

When making vertical bead welds, it is necessary to maintain the proper angle between the electrode and the base metal to deposit a good bead. In welding upward, the electrode should be held at an angle of 90° to the vertical. When weaving is necessary, the electrode should be oscillated with a "whipping up" motion. In welding downward, bead welds should be made by holding the top end of the electrode at an angle of about 15° below the horizontal to the plate with the arc pointed upward toward the oncoming molten metal. When a weave bead is necessary, in welding downward, a slight semicircular movement of the electrode is necessary.

In depositing a bead weld in the horizontal plane on a vertical plate, the electrode should be held at right angles to the vertical. The top of the electrode should be tilted at an angle at about 15° toward the direction of welding to obtain a better view of the arc and crater. The welding currents used should be slightly less than those required for the same type and size of electrode in flat position welding.

Groove Welds (Butt Joints)

Butt joints in the vertical position are "groove welded" in a manner similar to the welding of butt joints in the flat position. To obtain good fusion with no undercutting, a short arc should be held, and the motion of the electrode should be carefully controlled.

Butt joints on beveled plates 1/4 in. in thickness can be groove welded by using a triangular weaving motion. In groove welding butt joints in the horizontal position on identical plates, a short arc is necessary at all times. The first pass is made from left to right or right to left, with the electrode held at an angle of 90° to the vertical plate. The second, third, and, if required, any additional passes are made in alternate steps, with the electrode held approximately parallel to the beveled edge opposite to the one being welded.

Fillet Welds

When making fillet welds in either tee or lap joints in the vertical position the electrode should be held at an angle of 90° to the plates or at an angle of up to 15° below the horizontal, for better control of the molten puddle. The arc should also be held short to obtain good penetration, fusion, and molten metal control.

In welding tee joints in the vertical position, the electrode should be moved in a triangular weaving motion. The joint should be started at the bottom and welded upwards. A slight hesitation in the weave, as shown in figure 6–37, will improve sidewall penetration and allow good fusion at the root of the joint. If the weld metal overheats, the electrode should be lifted away quickly at short rapid intervals without breaking the arc. This will allow the molten metal to solidify without running down. The electrode should be returned immediately to the crater of the weld to maintain the desired size of the weld.

When more than one layer of metal is needed to make a vertical tee weld, different weaving motions may be used. A slight hesitation at the end of the weave will result in good fusion without undercutting the plate at the edges of the weld. When welding lap welds in the vertical position, the same procedure is followed as that outlined for welding vertical tee joints, except that the electrode is directed more toward the one vertical plate. Care should be taken not to undercut either plate, or to allow the molten metal to overlap the edges of the weave. On heavy plate, lap joints require more than one layer of metal.

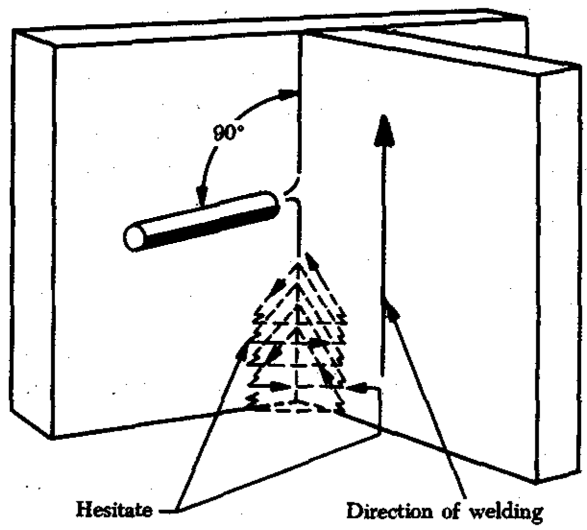


FIGURE 6–37. Vertical tee joint fillet weld.

WELDING OF AIRCRAFT STEEL STRUCTURES

Oxyacetylene or electric arc welding may be utilized for repair of some aircraft structures, since most aircraft structures are fabricated from one of the weldable alloys; however, careful consideration should be given to the alloy being welded since all alloys are not readily weldable. Also, certain structural parts may be heat treated and therefore could require special handling. In general, the more responsive an alloy steel is to heat treatment, the less suitable it is for welding because of its tendency to become brittle and lose its ductility in the welded area. The following steels are readily weldable: (1) Plain carbon of the 1000 series, (2) nickel steel of the SAE 2300 series, (3) chrome/nickel alloys of the SAE 3100 series, (4) chrome/molybdenum steels of the SAE 4100 series, and (5) low-chrome/molybdenum steel of the SAE 8600 series.

Aircraft Steel Parts Not To Be Welded

Welding repairs should not be performed on aircraft parts whose proper function depends on strength properties developed by cold working, such as streamlined wires and cables.

Brazed or soldered parts should never be repaired by welding, since the brazing mixture or solder can penetrate the hot steel and weaken it.

Aircraft parts such as turnbuckle ends and aircraft bolts which have been heat treated to improve their mechanical properties should not be welded.

Repair of Tubular Members

Welded steel tubing can usually be spliced or repaired at any joint along the length of the tube, but particular attention should be given to the proper fit and alignment to avoid distortion. Some of the many acceptable practices are outlined in the following paragraphs.

Dents at a steel tube cluster-joint can be repaired by welding a specially formed steel patch plate over the dented area and surrounding tubes, as shown in figure 6–38.

To prepare the patch plate, a section of steel sheet is cut from the same material and thickness as the heaviest tube damaged. The reinforcement plate is trimmed so that the fingers extend over the tubes a minimum of one and one-half times the respective tube diameters (figure 6–38). The reinforcement plate may be formed before any welding is attempted, or it may be cut and tack welded to one or more of the tubes in the cluster-joint, then heated and formed around the joint to produce a smooth contour. Sufficient heat should be applied to the plate during the forming process so that no gap exists. If a gap exists it should not exceed $\frac{1}{16}$ in. from the contour of the joint to the plate. After the plate is formed and tack welded to the cluster-joint, all the reinforcement plate edges are welded to the cluster-joint.

Repair by Welded Sleeve

This type of repair of a dented or bent tube is illustrated in figure 6–39. The repair material selected should be a length of steel tube sleeving having an inside diameter approximately equal to the outside diameter of the damaged tube and of the same material and wall thickness. This sleeve reinforcement should be cut at a 30° angle on both ends so that the minimum distance of the sleeve from the edge of the crack or dent is not less than one and one-half times the diameter of the damaged tube.

After the angle cuts have been made to the ends, the entire length of the reinforcement sleeve should be cut, separating the sleeve into half-sections (figure 6–39). The two sleeve sections are then clamped to the proper positions on the affected areas of the original tube. The sleeve is welded along the length of the two sides, and both ends are welded to the damaged tube, as shown in figure 6–39.

Repair by Bolted Sleeve

Bolted sleeve repairs on welded steel tubular structure are not recommended unless specifically authorized by the manufacturer or the Federal Aviation Administration. The material removed by drilling the boltholes in this type of repair may prove to weaken the tubular structure critically.

Welded-Patch Repair

Dents or holes in tubing can be safely repaired by a welded patch of the same material but one gage thicker, as illustrated in figure 6–40, with the following exceptions:

(1) Do not use a welded patch to repair dents deeper than one-tenth of the tube diameter, dents that involve more than one-fourth of the tube circumference, or those longer than the tube diameter.

(2) Use welded-patch repairs only if dents are free from cracks, abrasions, and sharp corners.

(3) Use welded-patch repairs only when the dented tubing can be substantially reformed without cracking before application of the patch.

(4) In the case of punctured tubing, use welded-patch repairs if the holes are not longer than the tube diameter and involve not more than one-fourth of the tube circumference.

Splicing Tubing by Inner Sleeve Method

If the damage to a structural tube is such that a partial replacement of the tube is necessary, the inner sleeve splice shown in figure 6–41 is recommended, especially where a smooth tube surface is desired. A diagonal cut is made to remove the damaged portion of the tube, and the burrs are removed from the edges of the cut by filing or similar means. A replacement steel tube of the same material and diameter, and at least the same wall thickness is then cut to match the length of the removed portion of the damaged tube. At each end of the replacement tube a $\frac{1}{8}$-in. gap should be allowed from the diagonal cuts to the stubs of the original tube.

A length of steel tubing should next be selected of at least the same wall thickness and of an outside

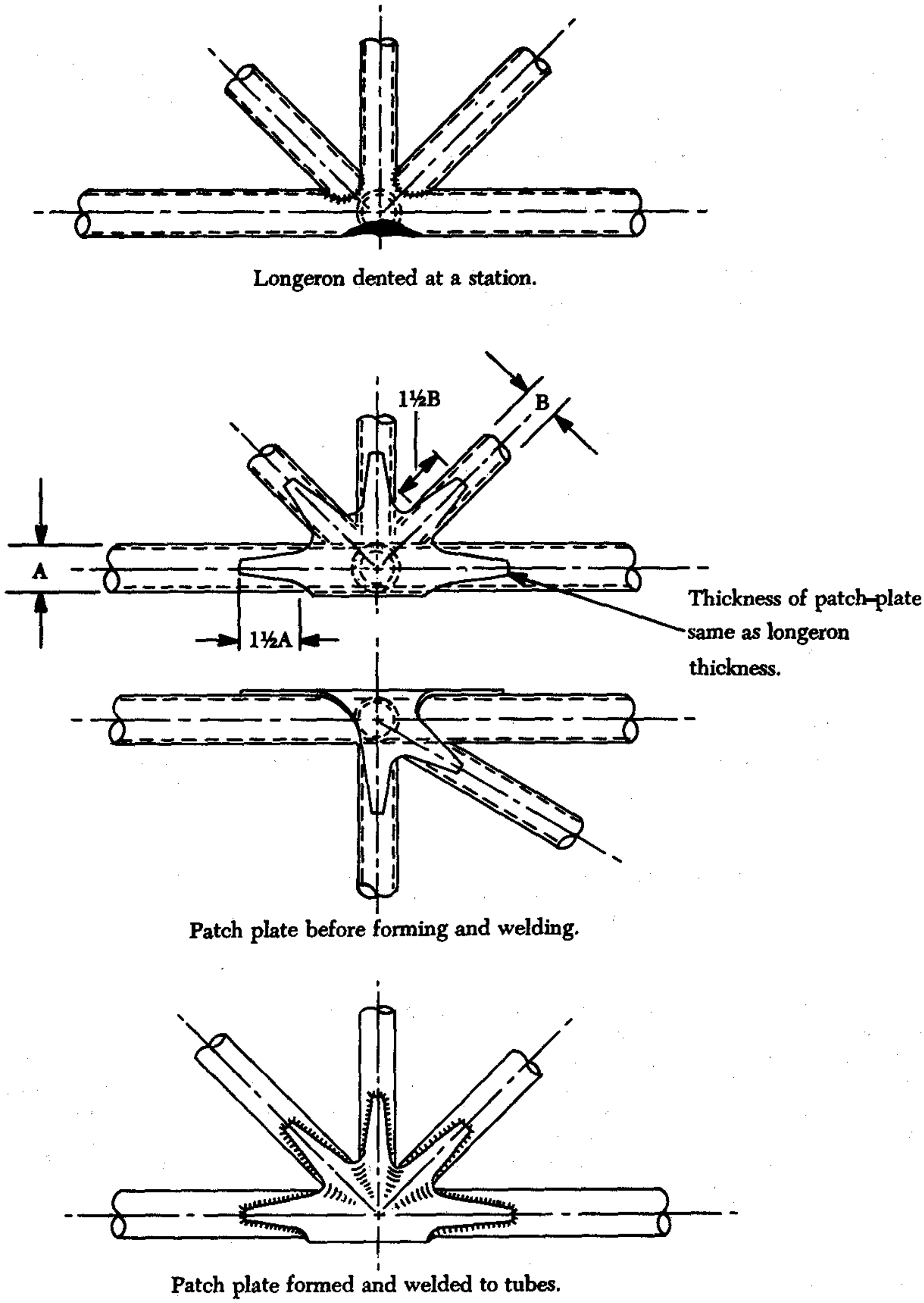


FIGURE 6–38. Repair of members dented at a cluster.

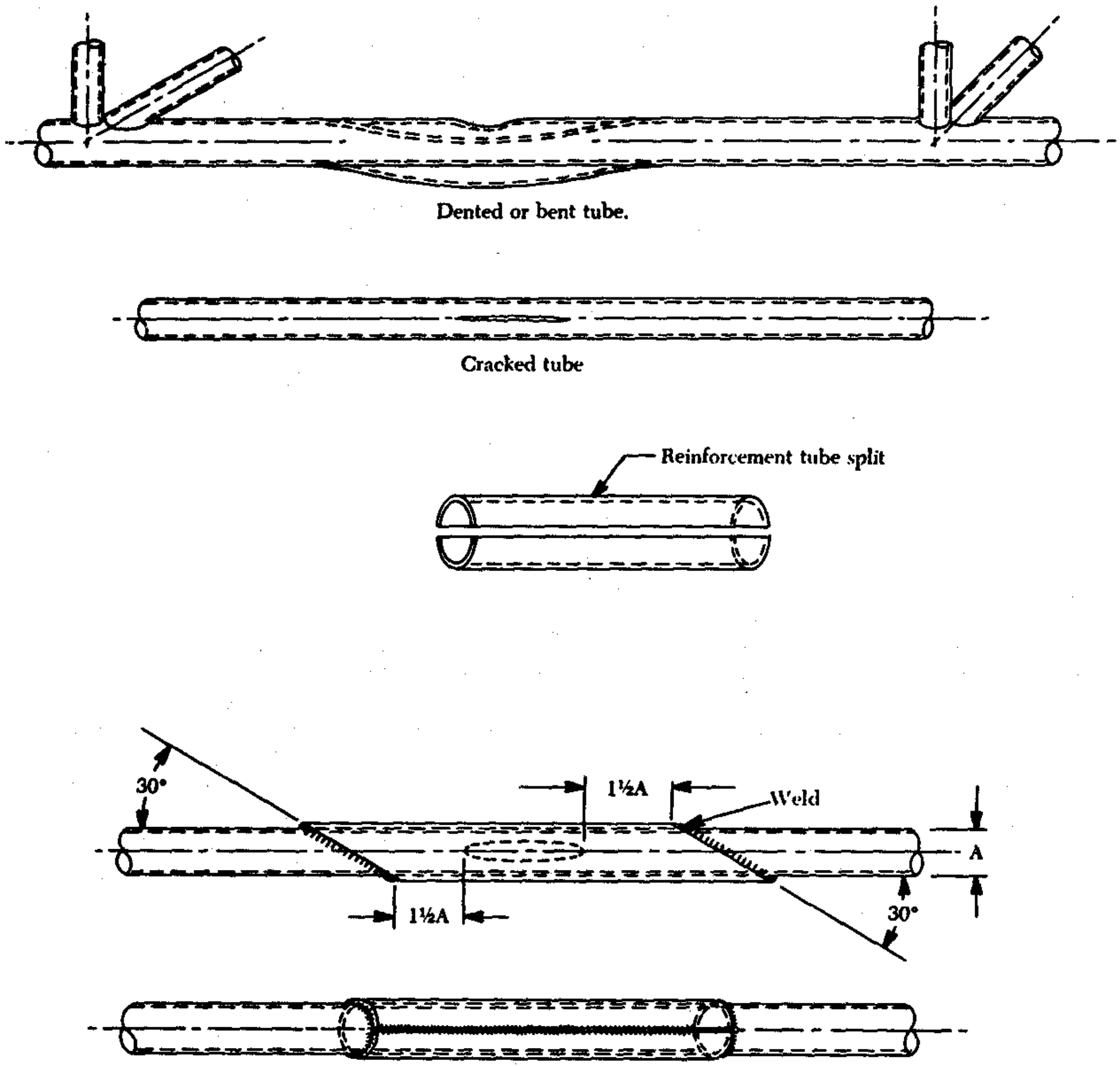


FIGURE 6–39. Repair by welded sleeve.

diameter equal to the inside diameter of the damaged tube. This inner tube material should be fitted snugly within the original tube. Cut two sections of tubing from this inner-sleeve tube material, each of such a length that the ends of the inner sleeve will be a minimum distance of one and one-half tube diameters from the nearest end of the diagonal cut.

If the inner sleeve fits very tightly in the replacement tube, the sleeve can be chilled with dry ice or in cold water. If this procedure is inadequate, the diameter of the sleeve can be polished down with emery cloth. The inner sleeve can be welded to the tube stubs through the ⅛-in. gap, forming a weld bead over the gap.

Engine Mount Repairs

All welding on an engine mount should be of the highest quality, since vibration tends to accentuate any minor defect. Engine-mount members should preferably be repaired by using a larger diameter replacement tube telescoped over the stub of the original member, using fishmouth and rosette welds. However, 30° scarf welds in place of the fishmouth welds are usually considered acceptable for engine mount repair work.

Repaired engine mounts must be checked for accurate alignment. When tubes are used to replace bent or damaged ones, the original alignment of the

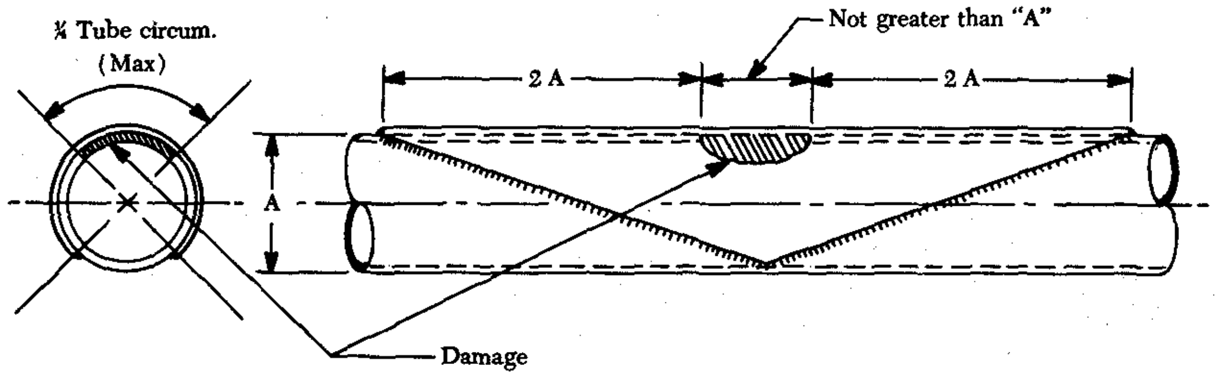


FIGURE 6–40. Welded-patch repair.

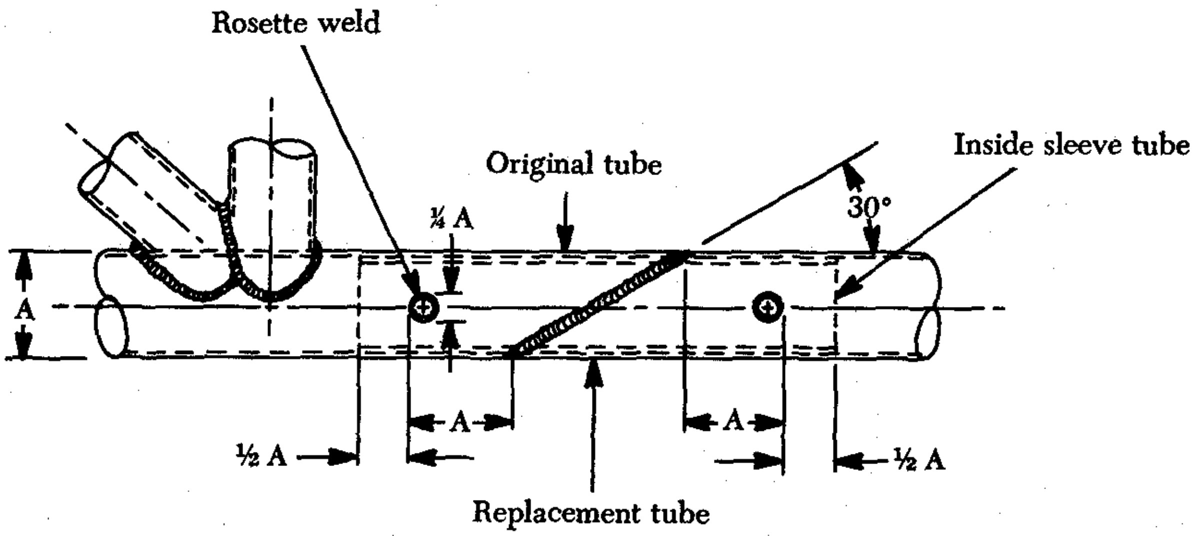


FIGURE 6–41. Splicing by inner-sleeve method.

structure must be maintained. This can be done by measuring the distance between points of corresponding members that have not been distorted, and by reference to the manufacturer's drawings.

If all members are out of alignment, the engine mount should be replaced by one supplied by the manufacturer or one built to conform to the manufacturer's drawings. The method of checking the alignment of the fuselage or nacelle points can be requested from the manufacturer.

Minor damage, such as a crack adjacent to an engine attachment lug, can be repaired by re-welding the ring and extending a gusset or a mounting lug past the damaged area. Engine mount rings which are extensively damaged must not be repaired, unless the method of repair is specifically approved by an authorized representative of the Federal Aviation Administration, or is accomplished using instructions furnished by the aircraft manufacturer.

Repair at Built-In Fuselage Fittings

An example of a recommended repair at built-in fuselage fittings is illustrated in figure 6–42. There are several acceptable methods for effecting this type of repair. The method illustrated in figure 6–42 utilizes a tube (sleeve) of larger diameter than the original. This necessitates reaming the fitting holes in the longeron to a larger diameter. The forward splice is a 30° scarf splice. The rear longeron is cut approximately 4 in. from the center line of the joint, and a spacer 1 in. long is fitted over the longeron. The spacer and longeron are edge-welded. A tapered "V" cut approximately 2 in. long is made in the aft end of the outer sleeve, and the end of the outer sleeve is swaged to fit the longeron and then welded.

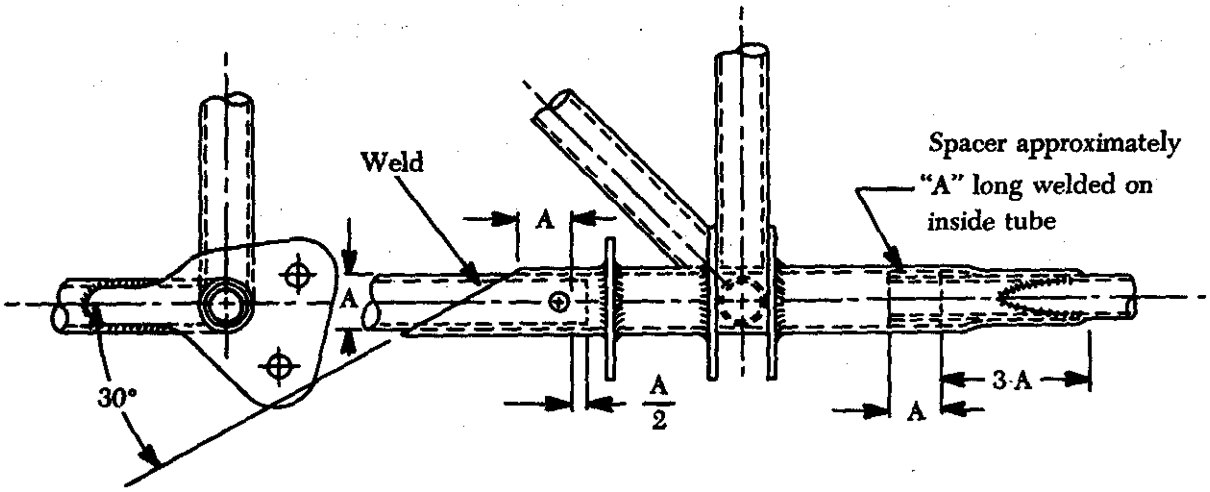
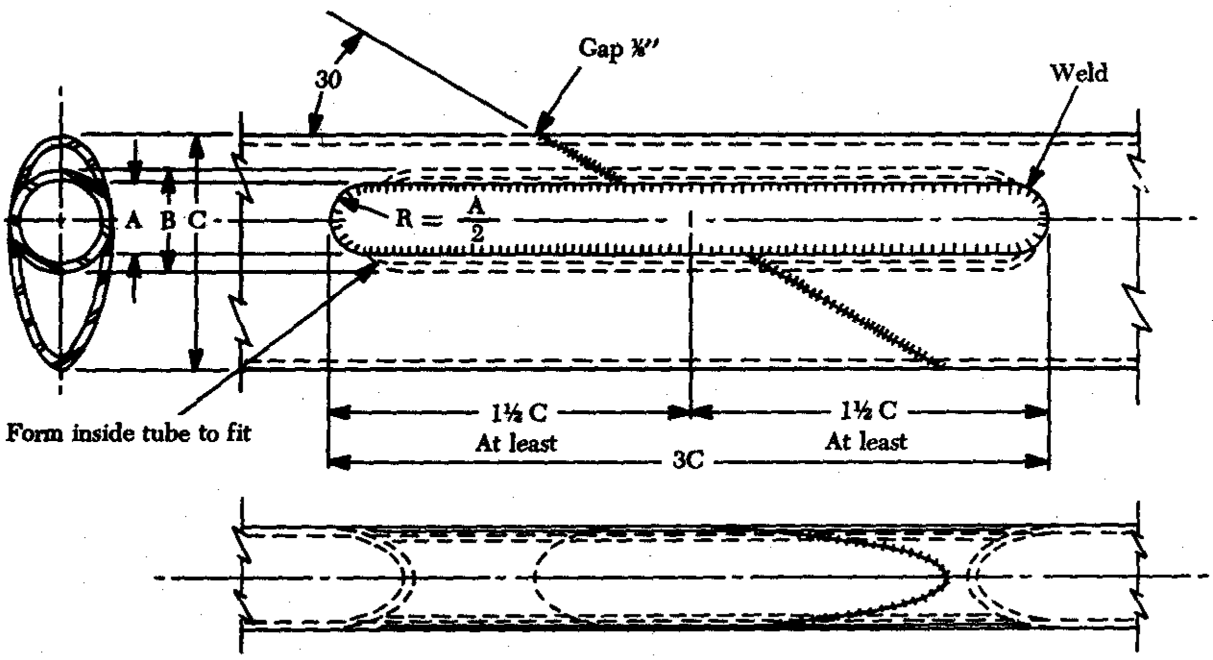


FIGURE 6–42. Repair at built-in fuselage fitting.

Landing Gear Repair

Landing gear made of round tubing is generally repaired using repairs and splices illustrated in figures 6–39 and 6–42. One method of repairing landing gear made of streamlined tubing is shown in figure 6–43.

Representative types of repairable and nonrepairable landing gear axle assemblies are shown in figure 6–44. The types shown in A, B, and C of this figure are formed from steel tubing and may be repaired by any of the methods described in this section. However, it will always be necessary to



A – Slot width (original tube)

B – Outside diameter (insert tube)

C – Streamline tube length of major axis

FIGURE 6–43. Streamlined tube splice on landing gear using round tube.

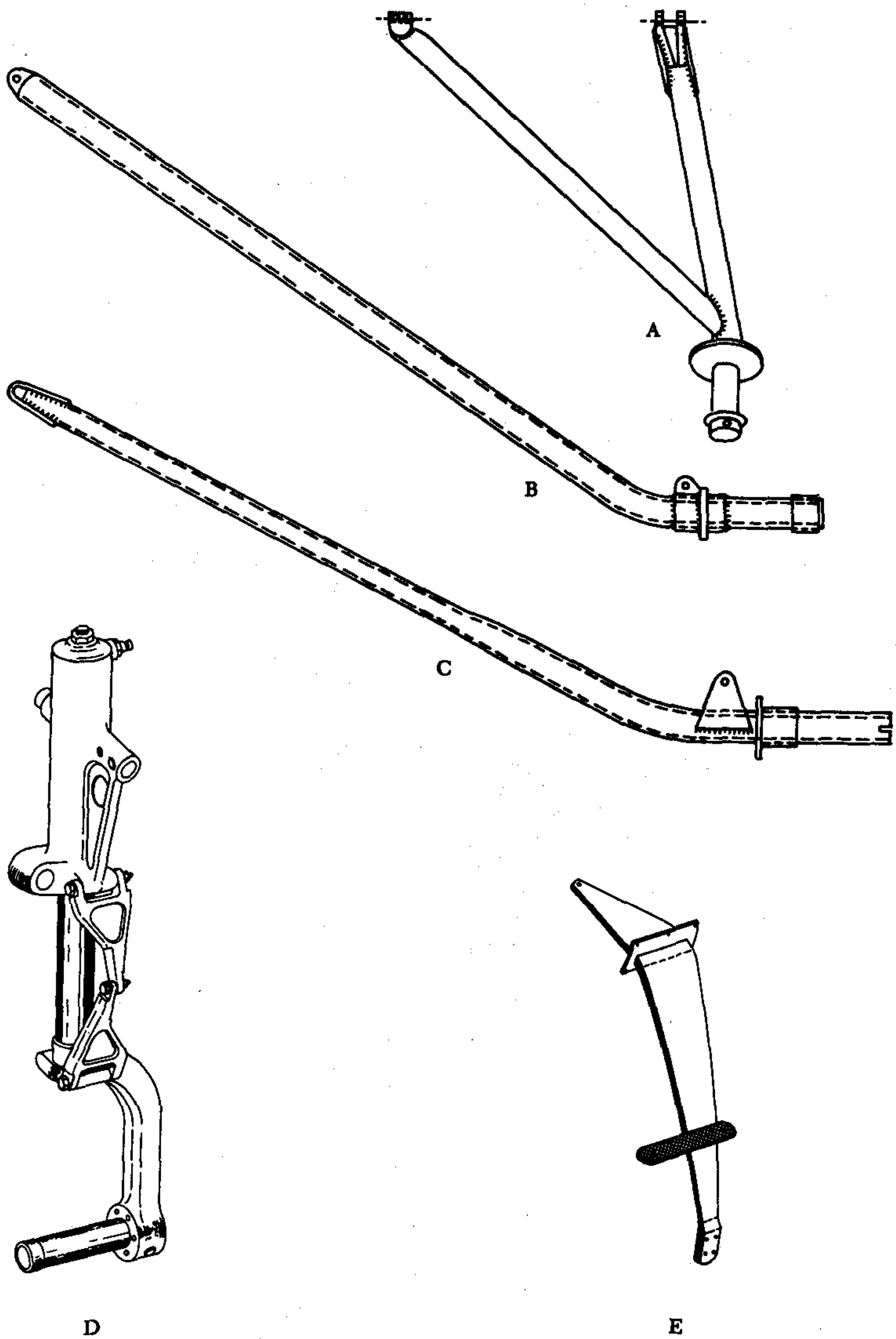


FIGURE 6-44. Representative types of repairable and nonrepairable assemblies.

ascertain whether or not the members are heat treated. Assemblies originally heat treated must be re-heat treated after welding.

The axle assembly shown in D of figure 6–44 is, in general, of a nonrepairable type for the following reasons:

(1) The axle stub is usually made from a highly heat treated nickel alloy steel and carefully machined to close tolerances. These stubs are usually replaced when damaged.

(2) The oleo portion of the structure is generally heat treated after welding and is perfectly machined to assure proper functioning of the shock absorber. These parts would be distorted by welding after the machining process.

A spring-steel leaf, shown in E of figure 6–44, supports each main landing gear wheel assembly on many light aircraft. These springs are, in general, nonrepairable and should be replaced when they become excessively sprung or are otherwise damaged.

Built-Up Tubular Wing or Tail Surface Spar Repair

Built-up tubular wing or tail surface spars can be repaired by using any of the splices and methods outlined in the discussion on welding of aircraft steel structures, provided the spars are not heat treated. In the case of heat treated spars, the entire spar assembly must be re-heat treated to the manufacturer's specifications after completion of the repair.

Wing and Tail Brace Struts

In general, it is advantageous to replace damaged wing-brace struts made either from rounded or streamlined tubing with new members purchased from the aircraft manufacturer. However, there is usually no objection from an airworthiness point of view to repairing such members properly. Members made of round tubes using a standard splice can be repaired as shown in figures 6–39 or 6–41.

Steel brace struts may be spliced at any point along the length of the strut, provided the splice does not overlap part of an end fitting. The jury strut attachment is not considered an end fitting; therefore, a splice may be made at this point. The repair procedure and workmanship should be such as to minimize distortion due to welding and the necessity for subsequent straightening operations. The repaired strut should be observed carefully during initial flights to ascertain that the vibration characteristics of the strut and attaching components are not adversely affected by the repair. A wide range of speed and engine power combinations must be covered during this check.